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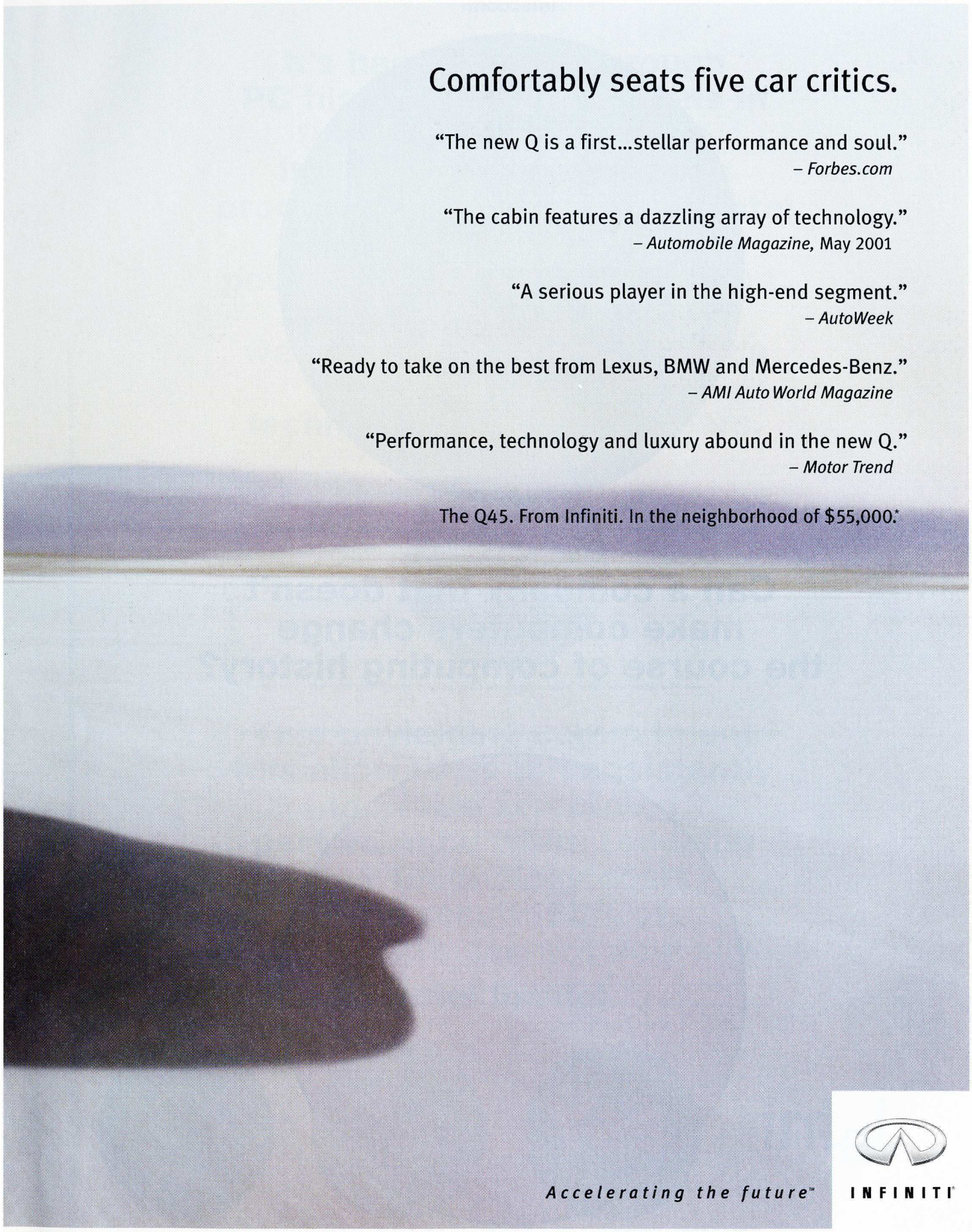
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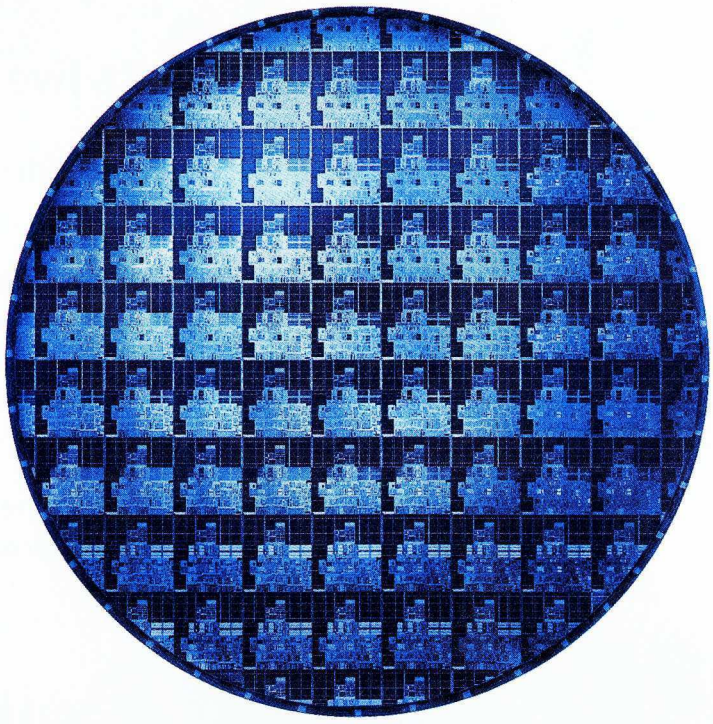


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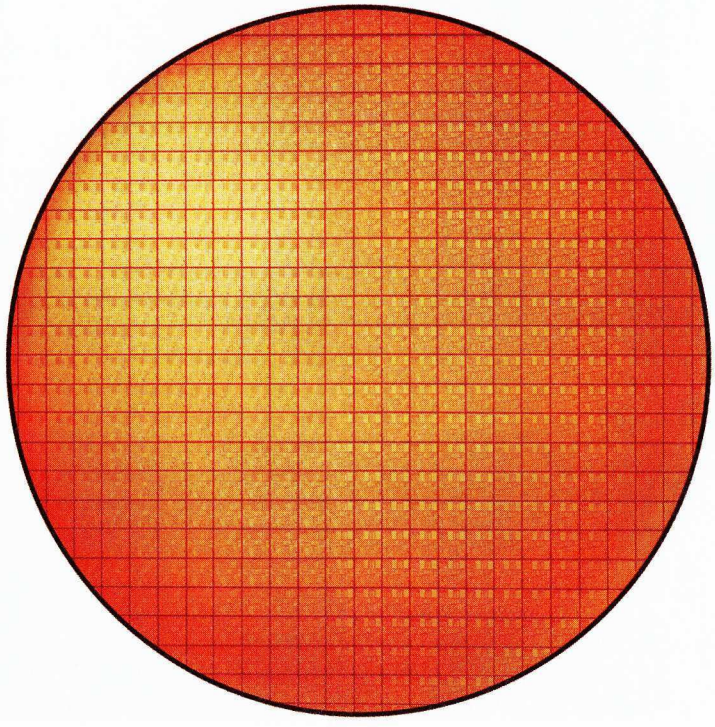
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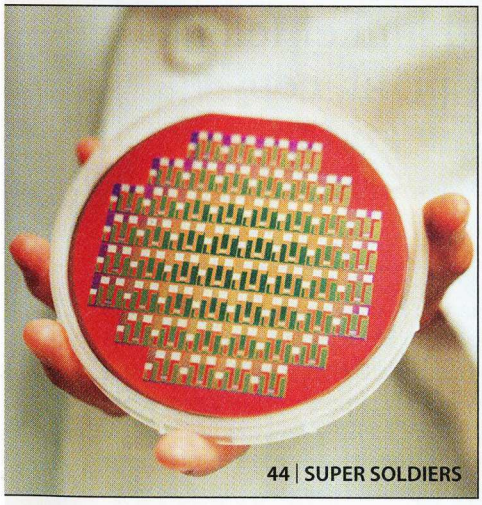
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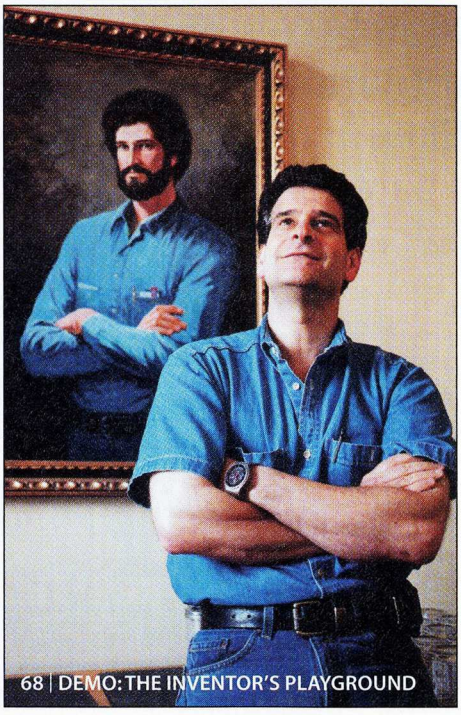


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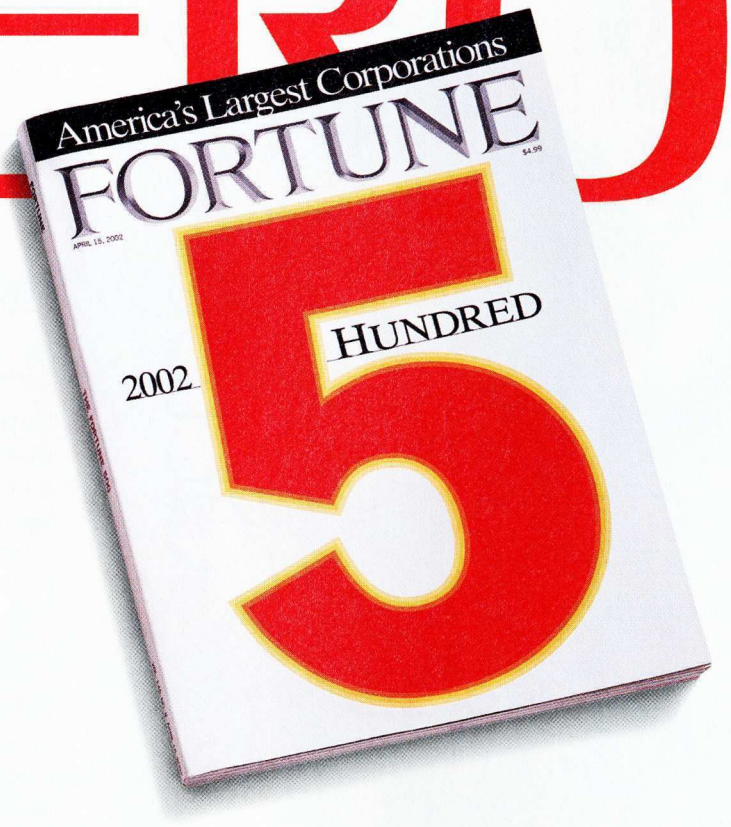
The Inventor's Playground

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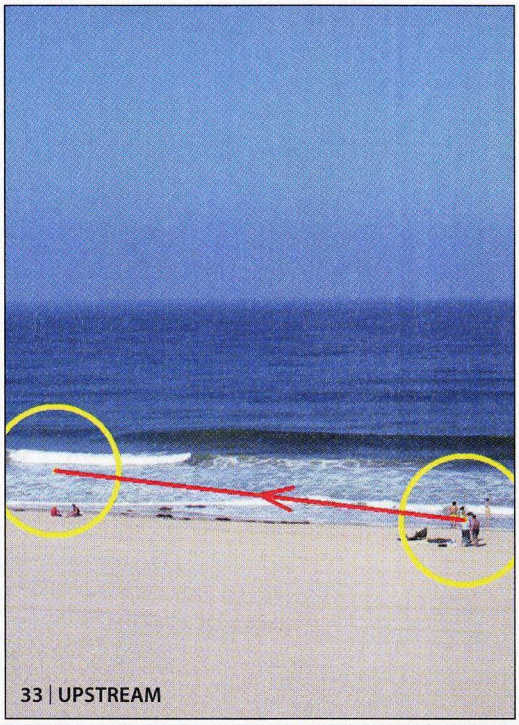
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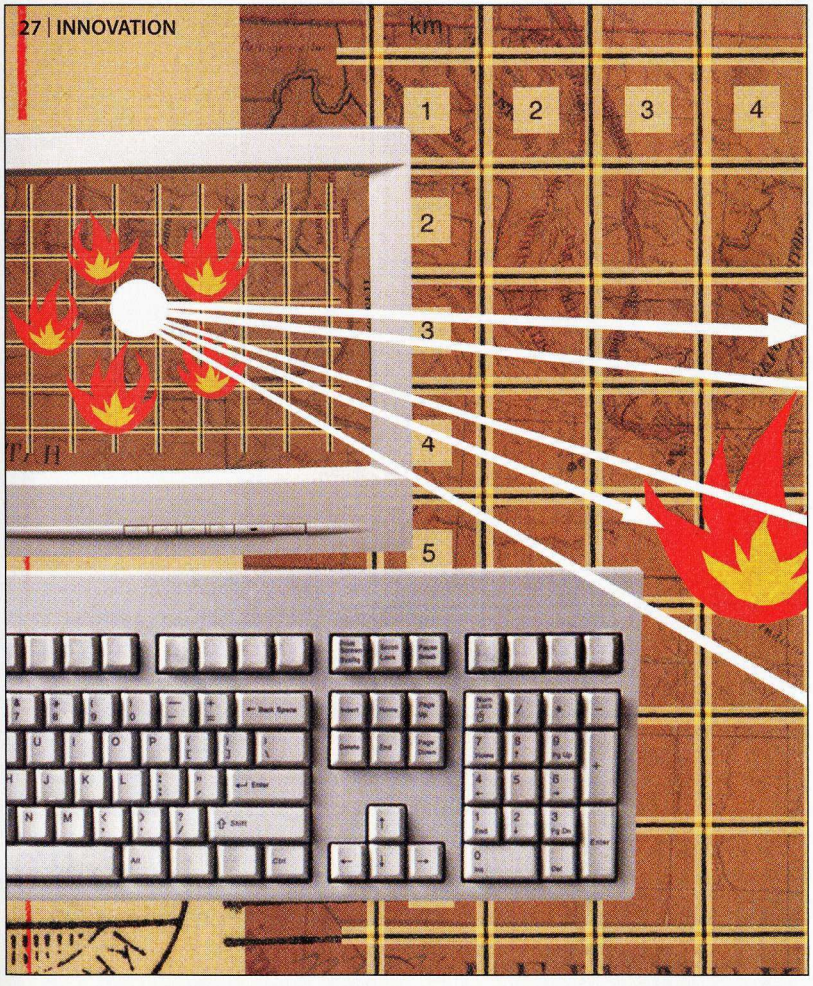
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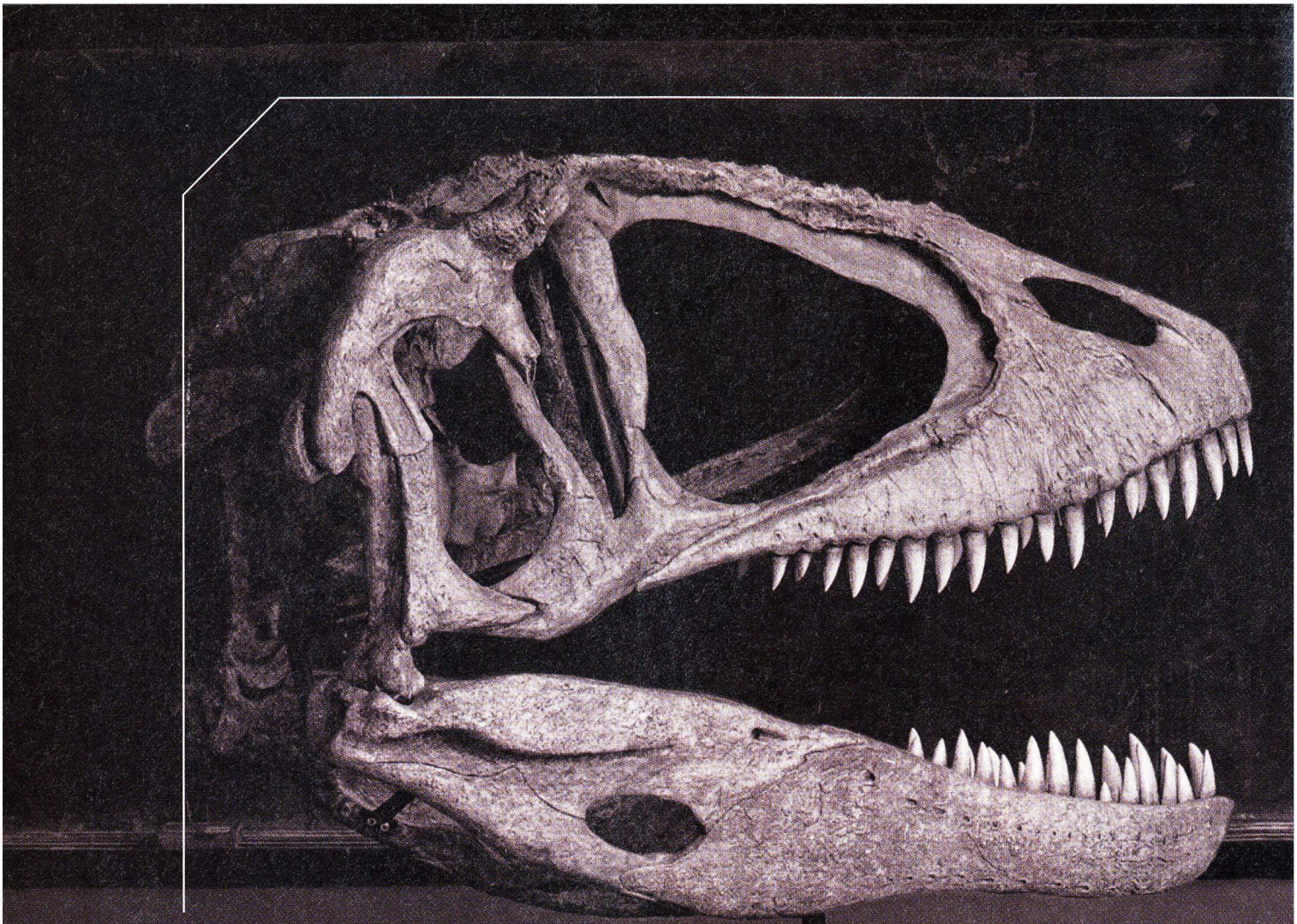
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Paleontologist Paul Sereno has encountered some of the weirdest creatures that ever walked the earth. Yet some of the scariest things he's discovered aren't likely to become extinct anytime soon. Sad to say, mutual fund management fees will probably outlast us all. That's why Dr. Sereno **was afraid of getting eaten alive.** So he turned to a company famous for keeping the costs down. That meant more money for him and less for the monsters.

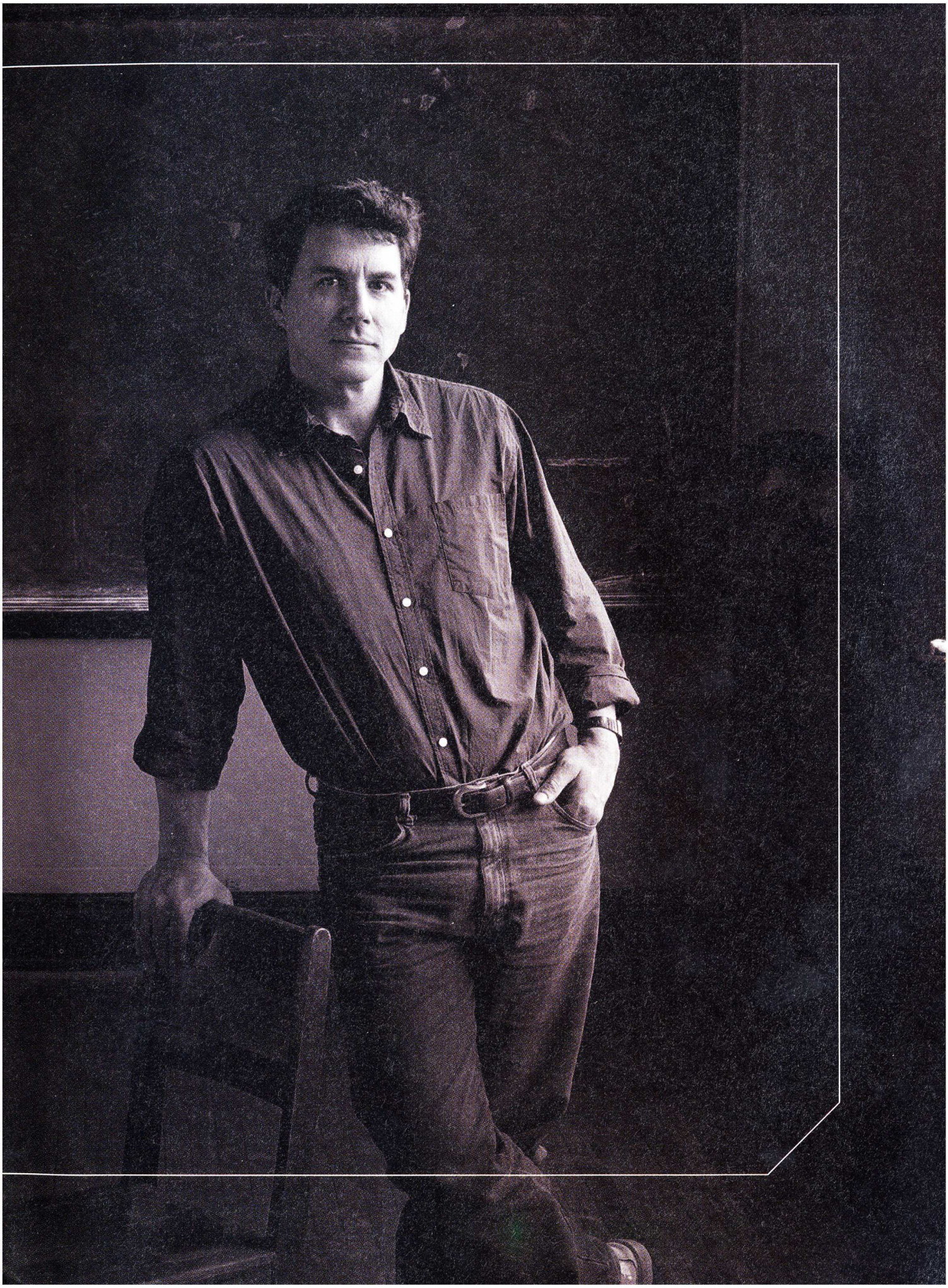
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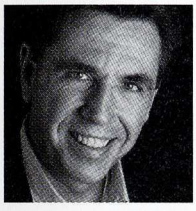
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THE MILITARY'S ROLE IN ACADEMIC RESEARCH

On June 12, 1940, Vannevar Bush entered the Oval Office to meet President Franklin Roosevelt. Bush, president of the Carnegie Institution, was on a mission. The Battle of Britain had begun, and Bush felt certain the United States would be drawn into the war. He also believed that the conflict would be a technological fight and that the distinct lack of cooperation between the U.S. military and civilian scientists had to be overcome in order to defeat Germany. To that end, he presented the president with a one-page sketch of a new government body that would make civilian scientists integral to the war effort. In less than ten minutes, the president told Bush, "Put 'OK FDR' on it."

So was born the National Defense Research Committee. It soon spawned an even larger body, the Office of Scientific Research and Development, with Bush at its head. Virtually all civilian research related to World War II—from fighting malaria to radar to the atomic bomb—came under its purview. It is safe to say that the Allies could not have won the war without the technologies developed under Bush's authority.

Which brings us to "Super Soldiers" *(p. 44)*, our feature story about a $50 million U.S. Army contract awarded to MIT to launch the Institute for Solider Nanotechnologies and develop new materials for use as artificial muscles, biowarfare sensors and communication systems. This is reminiscent of the projects that Bush's wartime groups ran: although it is targeted at well-defined military applications, it gets at fundamental issues in technology. But the importance of civilian scientists to applied military research was not the main lesson Bush taught the nation. Rather, it was more the opposite—that the payoffs for the economy and even security are greatest when the government funds less-applied, less-directed university research.



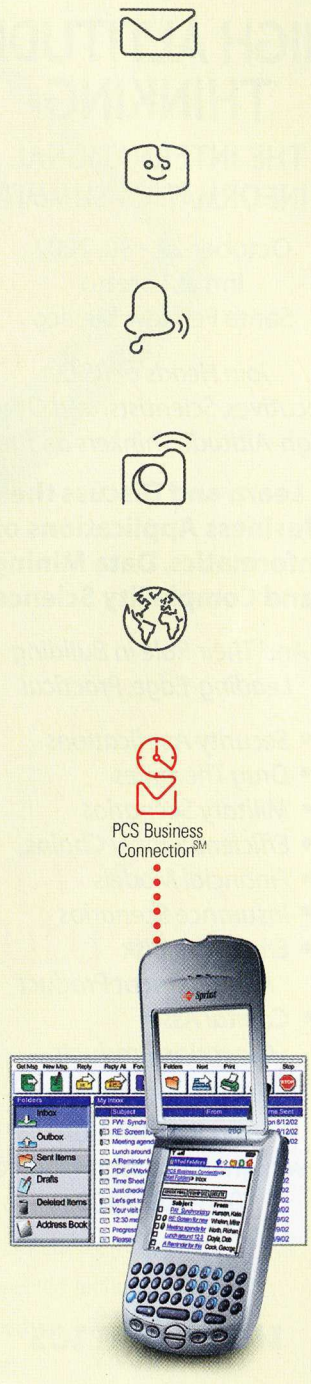
The success of Bush's scientists, many from universities, led to a huge increase in federal funding of academic research. The postwar course was set by the Office of Naval Research and the new National Science Foundation. Ever since, these and other groups, including the Defense Advanced Research Projects Agency, have generally operated on the guiding principle that Uncle Sam should invest in less-directed university research—even in defense matters. As General Dwight Eisenhower noted in 1946, civilian scientists "are more likely to make new and unsuspected contributions to the development of the army if detailed directions are kept to a minimum."

We have reaped the rewards of this approach for half a century—through military-sponsored projects that spawned everything from the maser (precursor to the laser) to the Internet. That is why efforts such as the Institute for Soldier Nanotechnologies can be important far beyond their specific military aims. This is research at the cutting edge of a young field, and the breakthroughs in artificial muscles that help soldiers carry their fallen comrades may one day help rescue workers lift obstacles.

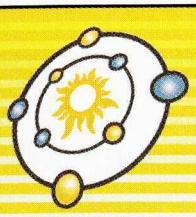
But despite such promise, a warning shot across the bow of research funding also seems warranted. In light of increased funding for defense measures since September 11, it is easy to imagine the military's backing research that is far more applied than that of the nanotechnology institute. The movement of universities toward shorter-term studies has been a source of worry in recent years, as industry has sponsored an increasing share of academic research, notes David M. Hart, associate professor of public policy at Harvard University's Kennedy School of Government. If the federal government moves more to the applied side as well, we risk sacrificing the fundamental breakthroughs that have long sustained economic growth. In the end, says Hart, "There's a battle that has to be fought all the time. In a way, it's really up to the universities to defend their turf, because who can blame the army for asking?"

And while universities should indeed be vigilant, so should we all. —*Robert Buderi*

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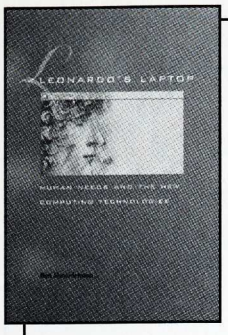


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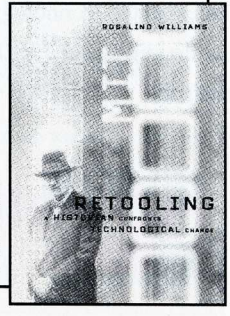
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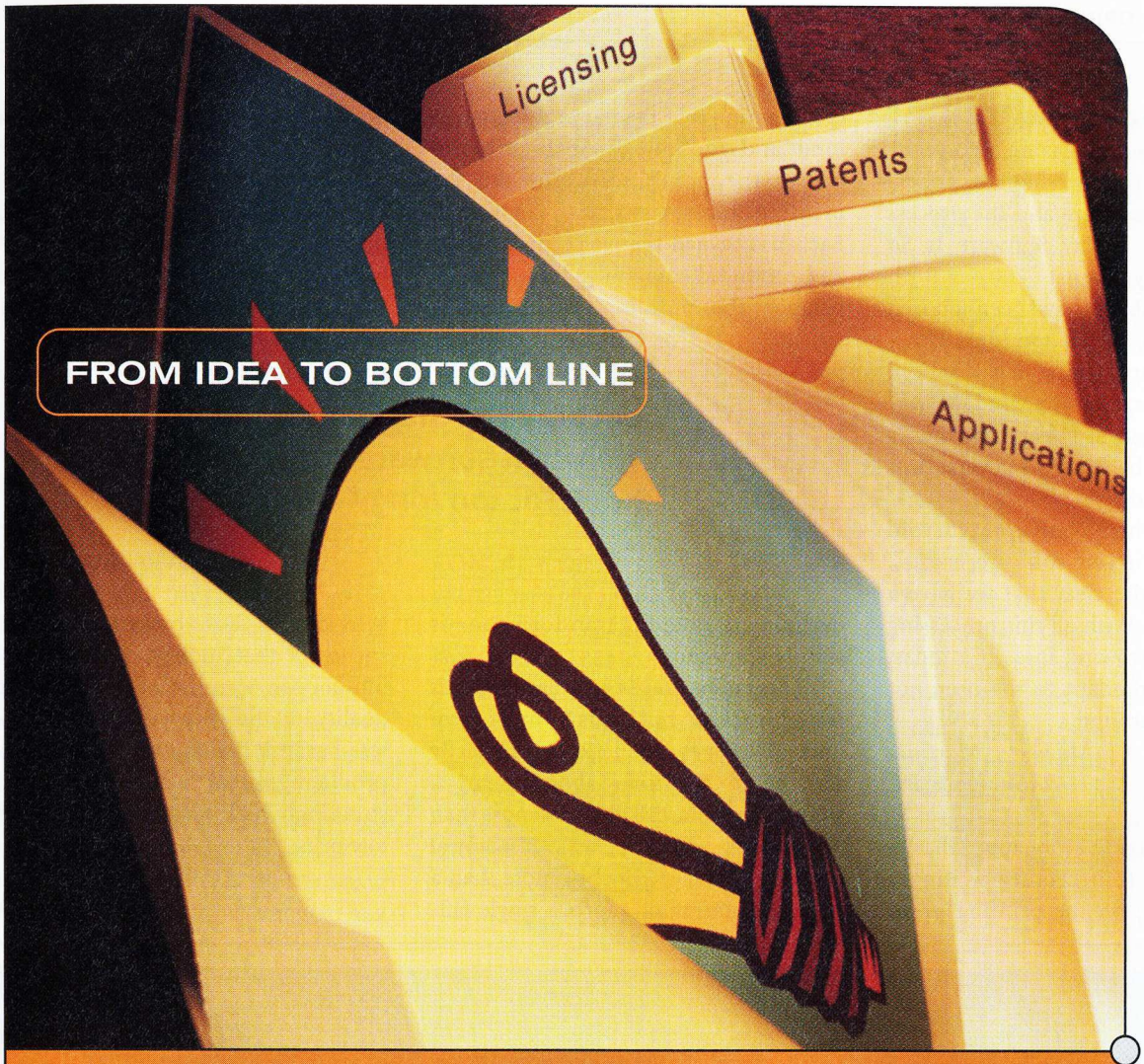
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LETTERS

INSIGHTS AND OPINIONS FROM OUR READERS

SOUNDING OFF ON SOFTWARE

Hats off to your magazine for an outstanding article on the flaws inherent in today's software and the process of its creation ("Why Software Is So Bad," *TR* July/August 2002). Both quality and usability have been ignored in this industry for far too long. However, aside from taking legal action, which will take years to wind its way through the courts, I fear that there's little that can be done to reverse this disturbing trend.

Indeed, when Nathan Myhrvold blames users for why software "sucks," he makes it quite clear that we have a long way to go. With all this processing power we're throwing into PCs today, software should adapt to the user, not the other way around.

Michael J. Martinez
Washington, DC

It's easy to imagine a previous Charles Mann in the 16th century writing a similar critique on the printing press, complaining that the damn thing is too loud and too messy. Such criticism misses the point: software, like the printing press, is transformational. Each has turned the world on its head and produced something far better. To belabor the piddling failures while declining to note the transformation is simply ignorance.

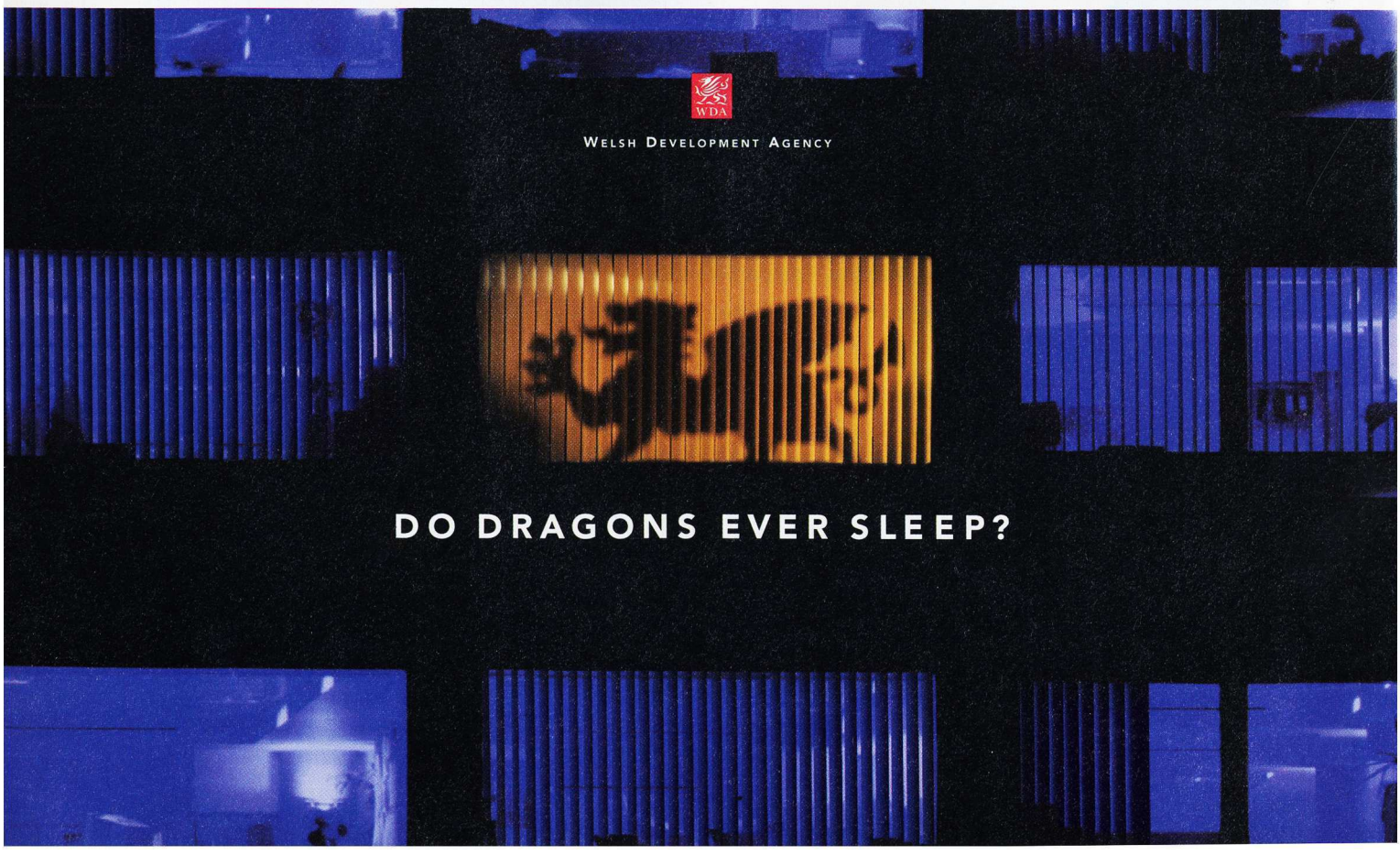


"What a great irony that Microsoft has become the Standard Oil of its day... We've let software companies off the hook for too long."

During the course of a day, Mann is served by many hundreds of millions of lines of code that function so perfectly that he never thinks about them. A simple telephone call exercises more than two million lines of code in his central office alone, the product of more than a man-millennium of effort. A single failure of any one of those lines could abort the call. Such aborts happen so seldom we are astounded when they do.

The software industry grew from near zero in 1965 to more than $350 billion a year by 1990, a growth pattern never before seen in economic history. Why did all those buyers queue up to spend all that money on software? A hint for Mr. Mann: it wasn't because the quality of the software was so low. It was because the software industry was producing breakthrough products of stunningly high quality at unbelievably low prices.

Tom DeMarco
Camden, ME



This article, which has been too long in coming, does a fine job of presenting a point of view. What a great irony that Microsoft has become the Standard Oil of its day, while for years we users faced the "blue screen of death" almost hourly. Having experienced the great technology bubble of 2000, people are no longer so awed by technology for its own sake, and now there is a backlash. We've let software companies off the hook too long.

Peter Tocco
Columbia, MD

THE GHANAIAN DIVIDE

I am greatly and truly indebted to G. Pascal Zachary ("Ghana's Digital Dilemma," *TR* July/August 2002) for shining light on the unwholesome darkness in which my people in Ghana live. As one of a few Ghanaians blessed to be living and getting an education here in the States, I, like most Americans, take so much of my exposure to technology for granted: sending e-mail, downloading music, doing research, listening to my favorite radio station, and so much more.

Zachary's article put me back in touch with the 20 million or so people I left back home when I came here in search of a brighter future. He has nudged the good conscience of the "powers that be" to explore this venture's expediency and provide an opportunity for natural talent whose only impediment to growth is limitation of resources.

Kobi Inkumsah
Houston, TX

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I agree with most of the issues raised in G. Pascal Zachary's article, but instead of talking about challenges, why don't we talk about solutions? One of the biggest issues is how to improve the government's policy toward development. Currently, there is nothing like a national policy concerning information technology. If we can get the president to talk about it, I think we will make a significant breakthrough.

Osei Darkwa
Oak Park, IL

A BETTER WAY

Actually, there is a simpler solution to Simson Garfinkel's worries about corporate control of personal e-mail addresses. ("Declare E-Mail Independence," *TR* July/August 2002). Why not just use a forwarding address? Many organizations give you a forwarding e-mail address that can be aimed at any real e-mail address you want.

Robert Nirenberg
Croton-on-Hudson, NY



International Rectifier is on the move in Europe. That's why we are investing more than $125m over the next five years at our facilities in Wales.

ALEX LIDOW
Chief Executive Officer
INTERNATIONAL RECTIFIER



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THE MARK OF SUCCESS

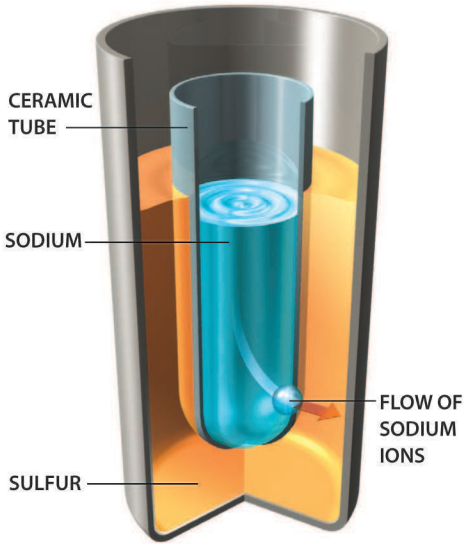
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POWER BACKUP

Japan-based NGK Insulators has transformed an experimental battery—which Ford Motor pursued for use in electric cars for more than 30 years—into a technology that could help manage the production of electric power. Each cell in the sodium and sulfur battery produces two volts when positively charged sodium ions pass through a ceramic tube and combine with negatively charged sulfur. Earlier versions of the technology could provide about 50 kilowatts, enough to supplement an office building's power supply during peak hours. By improving the ceramic's purity, NGK was able to reduce its thickness by 25 percent, to 1.3 millimeters. That in turn lowered its electrical resistance. The reduced resistance, combined with an altered design, allows the new battery to switch on in less than a millisecond and deliver 250 kilowatts, enough to supply backup juice during temporary power failures. This summer, NGK brought one of the new batteries on line for U.S. utility provider American Electric Power at one of its plants in Ohio.



A thinner ceramic tube speeds the flow of ions.



A new polymer helps this disc stand up to lasers.

HOLOGRAPHIC DISCS

One of the chief obstacles to the commercial development of holographic data storage, with its potentially vast capacity, may be starting to crumble. Holographic storage requires a photosensitive material in which specially modulated light beams can etch the data-bearing patterns that form when they intersect. Researchers at Aprilis, a Polaroid spinoff in Maynard, MA, think they've found just the thing: a silicone-based polymer that holds three to four times more data than competing holographic materials and that shrinks very little when struck by a data-writing laser. In other systems, shrinkage is a problem that introduces errors into recorded data.

"For holographic data storage to be successful, we needed to develop an entirely new material," says Aprilis cofounder Parag Mehta. Prototype devices using Aprilis's material store close to 200 gigabytes on a CD-sized disc—about 300 times as much as a conventional CD-ROM holds. Aprilis plans to supply commercial partners with its photopolymer and expects to see devices incorporating the material on the market in the next year or two.

OLEDS ON THE MOVE

Automobile and airplane display panels could soon get a face-lift from a new breed of organic light-emitting diodes, or OLEDs. Existing versions of the organic diodes are used in some cell phones but tend to burn out at high temperatures. By combining different materials, researchers at the Xerox Research Centre of Canada in Mississauga, Ontario, have developed an organic diode that can survive at up to 80 °C for 10,000 hours, says Xerox researcher Tony Paine. That's a tenfold improvement that could open the door to wider use of the technology. Unlike today's ubiquitous liquid crystal displays, organic light-emitting diodes can be viewed from any angle; they also use less power, generate brighter, sharper images and "switch" images faster for smoother video. In the next year or two, Xerox researchers aim to incorporate their technology into displays.

SUPER SUPERCAPACITOR

Supercapacitors store and disgorge electricity faster than batteries, and they are finding their way into everything from cars to cell phones. Now researchers at the Paul Scherrer Institute, a government lab in Villigen, Switzerland, have developed a version that delivers 15 kilowatts per kilogram in just 10 milliseconds. That's "triple what other supercapacitors can do," says Martin Carlen, head of applied physics at ABB Corporate Research in Baden-Daettwil, Switzerland, which cosponsored the research.

A supercapacitor stores energy as concentrations of electrons at the surfaces of electrodes bathed in an electrolyte solution. The Swiss device gains its advantage from the structure of its electrodes: they have pores that are the optimal size for storing electrons and are made entirely of a material called glassy carbon. Other supercapacitors' electrodes contain layers of different materials. Elimination of these layers lowers the supercapacitor's electrical resistance and boosts its efficiency. ABB is seeking to license the invention to help preserve battery life in devices such as cell phones where space is at a premium.



A supercapacitor with superior capacity.

COURTESY OF THE PAUL SCHERRER INSTITUTE (SUPERCAPACITOR); COURTESY OF D. W. ROTH (SUPERDISCS); SLIM FILMS (ILLUSTRATION)



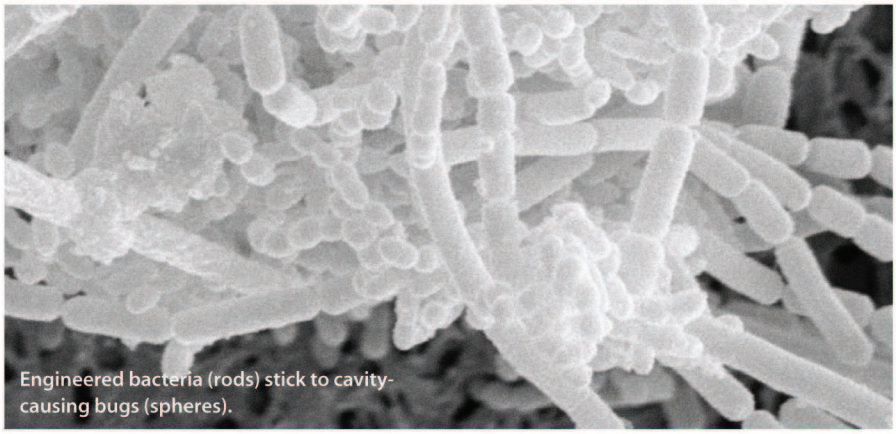
A rooftop router is part of a new wireless network.

BROADBAND AUTO

At a Kokomo, IN, test track that is run by automotive supplier Delphi, drivers can listen to FM, AM or Internet radio, while their back seat passengers watch digital videos. MeshNetworks in Maitland, FL, is developing one of the first wireless networks capable of transmitting broadband data to vehicles traveling at highway speeds. In conventional cellular-data networks, a radio must communicate directly with an Internet gateway, limiting how far a user can travel before the connection breaks. But in a so-called mesh network, gateways and routers—and even the radios in different cars—recognize and talk to each other automatically, passing data along to their final destination. This increases the distance data can travel. Delphi also envisions using the system to transmit engine data to mechanics or to help drivers navigate without global positioning system software. MeshNetworks expects to begin building the wireless networks over the next year, and Delphi says the technology might appear in 2006 car models.

DERMADOCTOR

Proteins such as erythropoietin and interferon are great at fighting disease, but it's difficult to deliver them with conventional needles or implanted pumps. Medgenics, in Misgav, Israel, has come up with an alternative: a "biopump," made from a patient's own skin, that can painlessly produce and deliver just the right amount of a protein drug. Medgenics takes a matchstick-sized strip of the patient's skin and cuts it into pieces called micro-organs, about 400 micrometers across. It then genetically engineers the micro-organs to produce the protein and monitors its daily production. After a week, the company implants just enough of the micro-organs in the patient to deliver the right dose. The biopump produces proteins at the measured rate for several months but can be removed at any point. Medgenics says it has proven the technology's feasibility through animal testing and has scheduled human trials for mid-2003. The company is also working on an automated device that will enable doctors to create patients' biopumps themselves. Medgenics plans to market the device within five years.



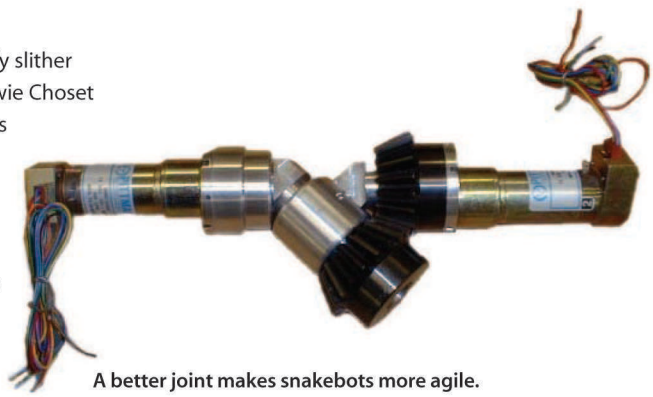
Engineered bacteria (rods) stick to cavity-causing bugs (spheres).

DAIRY MOUTHWASH

Soon a spoonful of yogurt will be able to protect your teeth against decay. Biologists at the Karolinska Institute in Stockholm, Sweden, have engineered *Lactobacillus zeae*—a bacterium commonly found in dairy products—to produce antibodies against *Streptococcus mutans*, the mouth bacterium that causes most cavities. When the researchers gave the modified *Lactobacillus* to rats, the antibodies on its surface bound to the *Streptococcus* on the rats' teeth, forming microscopic clumps that slid down the animals' throats. Immunologist Lennart Hammarström hopes to test the treatment next year in people with underactive salivary glands, such as patients undergoing radiation treatment for head and neck cancer, who have a greater risk of developing cavities. The Swedish team is also engineering *Lactobacillus* to produce antibodies against Rotavirus, which causes severe diarrhea in children, and *Helicobacter pylori*, a bacterium that causes ulcers and stomach cancer. Patients will take pills or eat yogurt containing modified *Lactobacillus*, which would colonize their stomachs. The treatment could prove cheaper and more effective than antibiotics, says Hammarström.

SLITHERBOTS

Thanks to new improvements in joint design, snakelike robots might more easily slither their way into collapsed buildings or toxic waste sites. Mechanical engineer Howie Choset of Carnegie Mellon University uses beveled gears to connect the joint around its circumference rather than at its center; the device's improved efficiency allows for the use of smaller motors. The result is a robot just five centimeters in diameter that is just as strong as and more maneuverable than today's best snakebots, which are 15 centimeters wide. Choset recently received $800,000 from the U.S. Department of Energy to develop a 10-joint, 1.2-meter-long snake robot. He expects to complete the first prototype this fall. If all goes well, Choset says, within two years his sensor-laden snakebot could be sensing radiation levels at toxic sites or beaming images from within rubble piles.

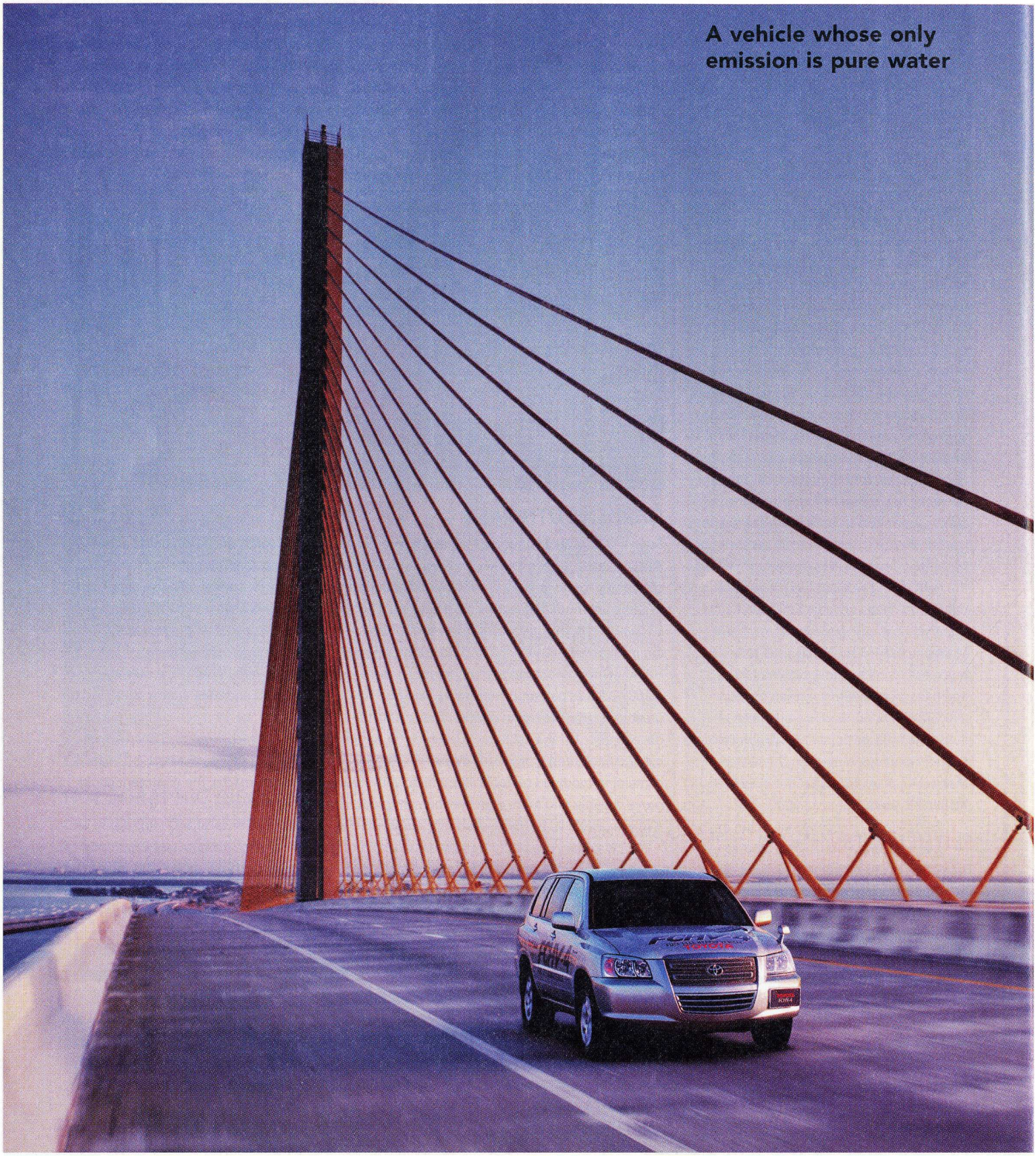


A better joint makes snakebots more agile.

COURTESY OF HOWIE CHOSET (SLITHERBOTS); COURTESY OF LENNART HAMMARSTROM (MOUTHWASH); COURTESY OF MESHNETWORKS (BROADBAND)

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OUTSMARTING THE CUSTOMER

After a pleasant dinner at a pricey restaurant, I was presented with an unusually informative bill. It displayed neatly printed calculations of what the tip would be at the 15, 20 or 25 percent level. How considerate!

Curious, I asked the waiter whether these informationally enhanced bills actually made any difference. He looked at me as if I had lost my mind: "All of our tips have gone up. People now know when they're stiffing us."

Clever. A tiny dose of cheap information significantly boosts the average tip. The value of this simple computational innovation is extraordinarily high. The waitstaff and the restaurant owners are obviously happier. And the customers don't appear to be unhappy even though they are, on average, paying more than they used to. (To be sure, the practice would have been swiftly discontinued if tips had declined.) At first glance, this seems to be a win-win info-innovation.



Then again, it also highlights a conflict for innovators struggling to strike a healthy balance between business profitability and customer sensitivity. Do innovations succeed because they make customers smarter or because they better exploit customer ignorance? To put the question more provocatively: do companies make more money from smart customers or stupid ones?

Financial-services firms, professional-services providers and health-care companies are constantly tormented by the trade-offs posed by taking advantage of customer ignorance. Introducing innovations that educate may be the dumbest thing a firm can do. Information becomes the enemy. It's one reason credit card companies, for example, resist legislation requiring them to disclose how long it would take cardholders to pay off their balances if only monthly minimums were paid. Concealing that information is more lucrative than revealing it.

Likewise, pharmaceutical companies are growing more concerned with compliance—ensuring that people take the right doses of their medication at the right time. For both regulatory and legal reasons, drug firms need to disclose the risks associated with improperly taking their medicines. Is delivering better information the best investment in compliance? Or as consumers become better educated about the drugs they're taking, do they switch to less expensive generic versions? Billions of dollars in health-care budgets depend on the answers.

Perhaps this recalls George Bernard Shaw's cynical epigram that "All professions are conspiracies against the laity." The conundrum here is that some innovations become more valuable the more customers know, while other innovations become worthless as customer IQ—Innovation Quotient—rises.

Most dangerous, innovators often don't know in advance whether keeping customers ignorant is more profitable than investing in educating them. Are pharmaceutical companies better off providing doctors with *everything* they need to know about a new therapeutic or providing just enough information to treat people safely? Proprietary innovators have tough choices.

For commodity offerings, however, the answer is clear: smart customers consistently pay lower prices. That's why all the large accountants and auditors launched consulting businesses. They had to offer value-added services to complement their commodities. That can create all kinds of conflicts.

But smarter customers also create smarter opportunities. Design, manufacturing and process engineers are always on the lookout for computer-aided-design tools that facilitate cost-effective creativity and integration. The more an engineer knows about using a tool, the more valuable that tool becomes.

Online investment companies such as Charles Schwab and E*Trade are the logical, digital extensions of a business bet that smarter customers are more ready, willing and able to pay a premium for an investment innovation. The virtual financial-services firms have economic incentives to provide information about innovative trading strategies so that customers can take better advantage of their improved ability to execute timely trades in the equities, options and derivatives markets.

Do innovations succeed because they make customers smarter or because they better exploit customer ignorance? Do companies make more money from smart customers or stupid ones?

As a general rule, however, ignorance can be profitable bliss for innovators who know far more than their customers do. Indeed, the role such "information asymmetries" play in distorting markets won the 2001 Nobel Prize in economics for Joseph Stiglitz, George Akerlof and Michael Spence. Their work confirms that when sellers know far more than buyers, unusual opportunities for great profits can arise.

This is especially true in the technology marketplace, where successful marketers may feel the incentive to confuse and complicate rather than to inform and educate. They aspire to asymmetry. Precisely because a Microsoft or an IBM may make more money from its "stupid" customers than from smart ones, it may have decidedly mixed feelings about how clever it wants its customers to become. Creating fear, uncertainty and doubt makes economic sense. That's why they do it.

Ultimately, the real leaders in innovation don't just educate their best customers, they learn how to collaborate with them. They collectively play with possibilities. They understand that innovation is about coevolution. But only the stupidest and most arrogant innovators believe that "smartest customer" equals "most profitable customer." There is a reason why P. T. Barnum made his money, even if he never did say "there's a sucker born every minute." Check please.



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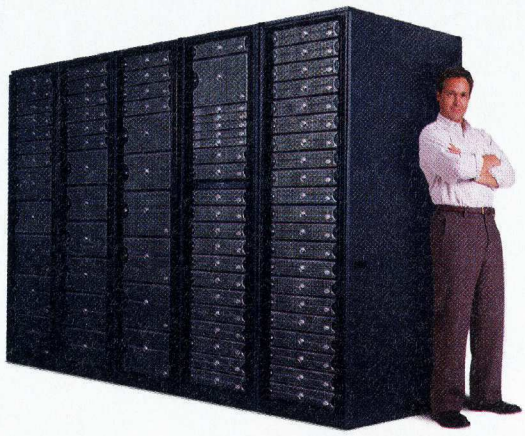
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HOW

Best Buy fine-tunes markdowns.



Q&A

Marsha Henry, Marketing Project Manager, Best Buy Co., Inc.

What challenges does Best Buy face when marking down products? Best Buy prides itself on having the latest consumer electronics on our shelves. But we have to work at it. We need to manage the entire assortment so that we have a good mix, and getting rid of products that are not obsolete while introducing new models is a delicate balancing act. In order to achieve that mix, we need effective price management – especially in the markdown process. Inventory levels, sales performance, seasonality, promotions, and various vendor-related issues are all factors that must be considered when creating a markdown. This is probably the greatest challenge facing consumer electronics retailers.

Why i2? We were looking for a way to better manage pricing throughout a product's life cycle. Best Buy was already using i2 solutions to manage value chain operations. i2 proposed a joint development program to create i2 Markdown Optimizer™ with Best Buy supplying information from the front lines of the retail industry and i2 providing the best-in-class technology.

What benefits are you seeing? Implementation of i2 Markdown Optimizer makes it possible for us to adjust a product's pricing to precisely match its sales patterns – not just across the franchise, but on a store-by-store basis. We can easily zero in on the optimum price for a single SKU in any of our 480+ stores. This means fewer markdowns and reduced inventories. It has tremendous value as a forecasting tool as well, enabling us to track the effect markdowns have on total sales and adjust our merchandise mix accordingly.

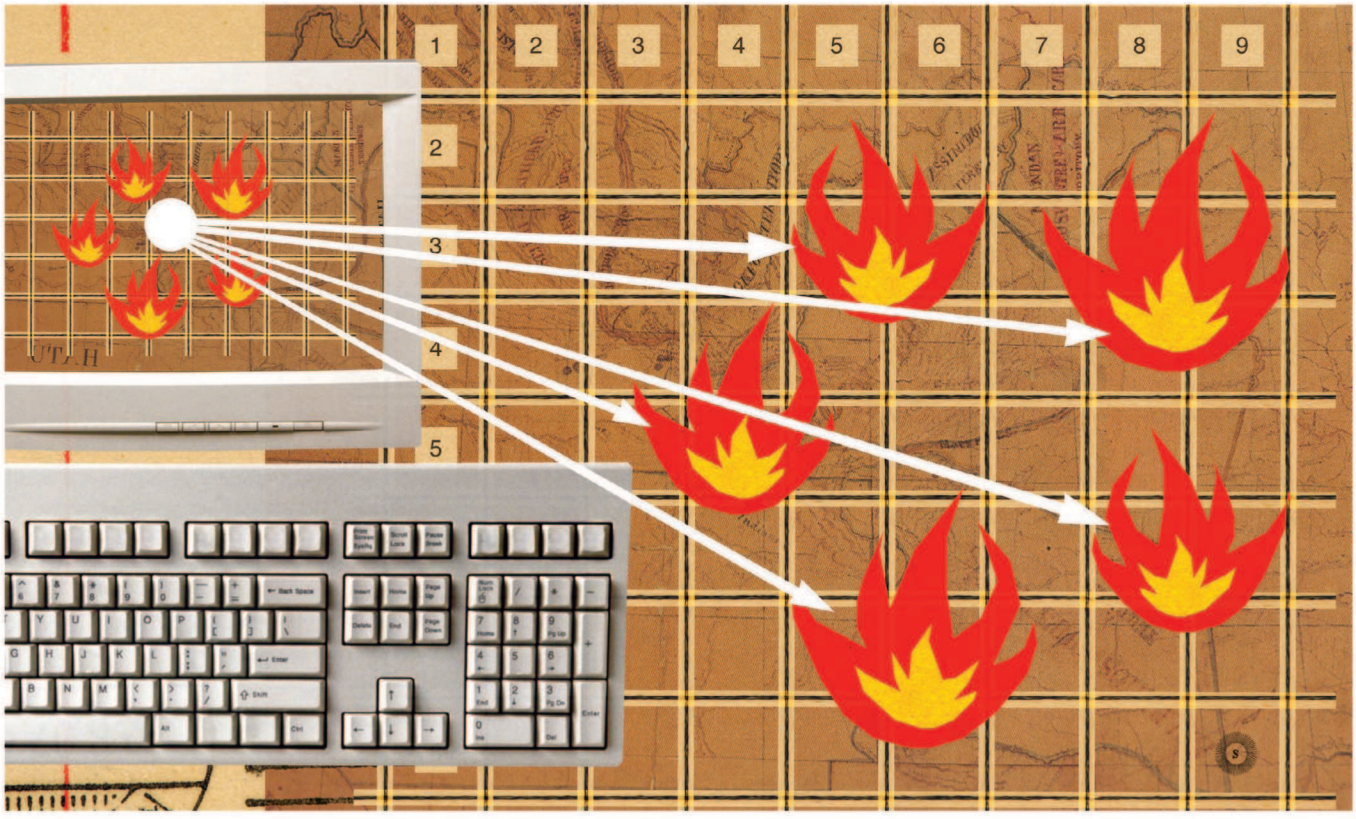
"We can adjust a product's pricing to precisely match its sales patterns – not just across the franchise, but on a store-by-store basis."

For a copy of this case study and others that demonstrate how i2 has delivered over $29 billion in audited value to its customers, visit www.i2.com. Or call 1-866-288-4896.

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JASON HOWARD STATTS

WILDFIRE IN THE FORECAST

Supercomputers could help firefighters stay ahead of the flames

Wildfire moves with the wind, as firefighters were grimly reminded in Arizona and Colorado last summer. New computer modeling could soon bring greater precision to the art of knowing which way the wind is blowing, potentially helping firefighters control blazes.

Computer simulations usually break down weather systems into grids of manageable cells, then calculate the interactions between adjacent cells. Most weather modeling uses a coarse grid, with cells 30 to 50 kilometers on a side. That's fine for predicting whether it's going to rain in your town. But when a fire is burning across complicated terrain, the ability to forecast winds, humidity and other atmospheric phenomena with a resolution of one kilometer or less could spell the difference between a fire contained and a fire gone wild. "If you want to predict the behavior of fire, you need high-resolution modeling," says forestry researcher Mark Finney of the U.S. Forest Service's Rocky Mountain Research Station in Missoula, MT.

In the 1990s Finney developed a model that predicts the behavior of fire on the basis of a number of variables, including weather. In Hawaii, researchers at the Maui Center for High-Performance Computing recently coupled this model, called Farsite, with atmospheric models that provide resolutions of one to two kilometers. A supercomputer runs the weather model to churn out detailed predictions of wind, humidity, cloud cover and other weather characteristics; these data then become input to Farsite, greatly abetting its precision. Although not yet used in the field, these coupled models could significantly improve the lot of firefighters, according to the Hawaii research. "This will give us a forecast of where the fire will move over the next 24 to 36 hours," says Duane Stevens, a meteorologist at the University of Hawaii at Manao.

Other groups are also coupling fire modeling with weather prediction. The Wildland Fire R&D Collaboratory includes about 20 organizations working to understand the interactions among fire, weather, terrain and flammable matter. Right now, the physics is too hard to simulate because of the numerous variables involved, including the type and dryness of the vegetation (known in the fire control world as "fuel") and the length of time since the last big fire. Moreover, not only are fires driven *by* weather, but large infernos also *influence* weather on a local scale. But Rich Wagoner, a scientist at the National Center for Atmospheric Research in Boulder, CO, isn't daunted. "We want to answer the question: what is this dance between fuel, fire and atmosphere?" —*Herb Brody*

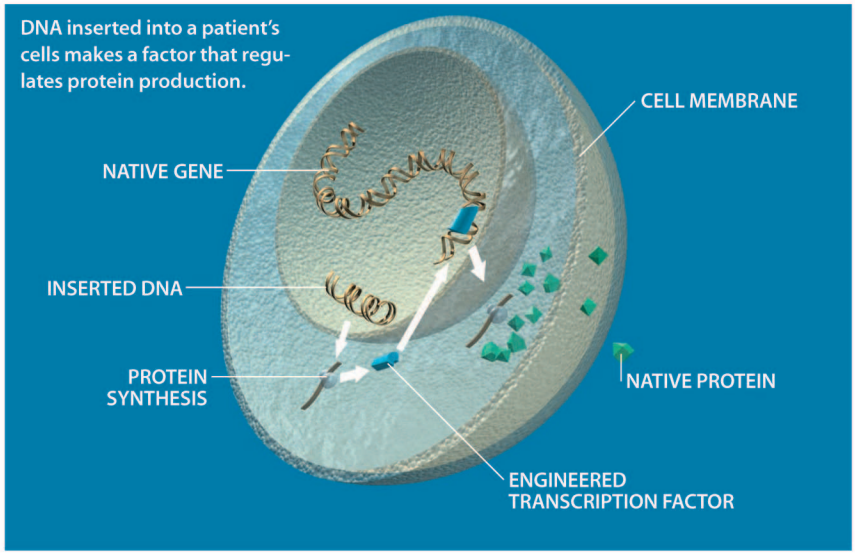
GIRDING THE GRID

ENERGY | Considering that a tree's touching an Oregon transmission line in 1996 sparked a blackout stretching from Mexico to Canada, it's not hard to imagine how coordinated attacks on the power grid could wreak continent-wide havoc. But within five years, new computer models could have the ability to respond to disasters in real time, throwing switches and rerouting power as repercussions spread. And that could help North America's interconnected grids protect themselves in the face of cascading failures, whether touched off by trees or terrorists.

The challenges involved in counteracting threats to the grid are "similar to playing a game of chess, but a lot harder," says Massoud Amin, area manager of infrastructure security at the Electric Power Research Institute, a utility-sponsored consortium in Palo Alto, CA. The institute recently tackled these challenges alongside researchers from two utilities and 26 universities, building new computer models that respond to disturbances by breaking up a large section of the grid into smaller "islands." This interrupts cascading failures and speeds restoration of service. In successful tests last year, the models detected simulated problems, calculated the likely domino effects and remotely tripped circuit breakers to isolate the disturbances and create islands. The models then balanced supply and demand within the islands by reducing power plant output or creating controlled brownouts.

The institute expects to put the models in control of actual emergency responses by 2005, when efforts to retrofit the electrical grid with electronic controls and sensors should also be farther along. Together, such advances may help to checkmate terrorists eyeing the grid. *—David Talbot*





THERAPY FOR GENES

Scientists commandeer protein-building at the source

BIOTECHNOLOGY | Frank Giordano's patients need new blood vessels: some have blocked arteries around their hearts, and others have poor circulation in their limbs. In a few cases, the Yale University cardiologist and molecular biologist has coaxed new vessels to grow using conventional gene therapy, injecting patients with genes that encode a natural protein called vascular endothelial growth factor. But he's most excited about a new treatment that, instead of relying on imported genes, stimulates the patients' own genes to work harder.

For now, Giordano's patients are strictly of the furry rodent variety, but the substances he's testing—engineered transcription factors that act directly on DNA to stimulate or block protein production—could herald a new approach to treating human disease. Sangamo BioSciences in Richmond, CA, designs transcription factors that bind uniquely to DNA sequences near specific medically relevant genes and turn protein production up or down at the source. "It's like a rheostat for any protein you want," says Casey Case, Sangamo's vice president of research.

Case says the technique has distinct advantages over existing gene therapy methods. In gene therapy—still an experimental treatment itself—genes are injected into a patient and provide instructions for making a single version of a protein; but native genes often code for several versions of a protein, each of which can play an important biological role. Because an engineered transcription factor turns on the body's own copy of a gene, all of these versions of a protein are made. Giordano says, for example, that mice producing all the variants of the blood vessel growth factor seem to have "more robust" vessels. And because Sangamo can engineer transcription factors for any genes—including those involved in cancer, diabetes, heart disease or nerve repair—"the sky's the limit" for other therapeutic applications, he says.

Paul Robbins, a gene therapist at the University of Pittsburgh, speculates that the approach could also be used in treatments for cancer and inflammation—and he predicts that with further research, the technique could offer even more control over gene expression. "This technology is at its very beginning," Robbins says.

Right now, an engineered transcription factor can reach a patient's DNA only if a gene encoding the factor is delivered to the relevant cells via gene therapy, but Sangamo is working to synthesize transcription factors that could be delivered intravenously. The company hopes to be ready for human trials of its vascular endothelial growth factor stimulator by late 2003, and if they pan out, cardiologists might have a way to help less furry patients build healthier hearts. *—Erika Jonietz*

JAMES YANG (ILLUSTRATION); JOHN MACNEILL (INFORMATION GRAPHIC)

CLEAR CONNECTION

WIRELESS | Anyone who's suffered broken cell-phone connections in urban areas already choked with voice traffic might doubt the imminence of the wireless Web. But researchers predict that a new technology called "multiuser detection" could greatly expand cell towers' capacity—increasing their range, their data transmission rates or the number of users they can handle.

Multiuser detection disentangles cell phone signals that interfere with each other, and "everybody who has an interest in cell phone systems is working on the implementation," says Peter Okrah, a researcher with wireless-equipment supplier Motorola. Ericsson, Nokia, Lucent Technologies, Intel and Microsoft have all investigated the technology, though the first to market may be smaller competitors such as industry supplier Ascom of Berne, Switzerland, or Mercury Computer Systems of Chelmsford, MA.

The central problem of cellular telephony is how to let users access the same tower without breaking up each other's calls. The most efficient solution is to assign a unique "code," or combination of radio frequencies, to each phone; a tower can key onto any one code and screen the others. In practice, however, buildings and other obstacles knock signals out of sync and cause them to interfere with each other.

The solution: subtraction. Since a tower knows the codes for all its current calls, it knows what the interference looks like and could remove it from a distorted signal. But that requires a lot of processing power—or some mathematical shortcuts.

Proposed remedies use both. Removing interfering phone signals one at a time would cause delays, but Mercury's computing platform, which deploys many microprocessors in parallel, can remove multiple signals at once. In simulations, it has increased a cell tower's capacity by 50 percent. Ascom's algorithm makes a series of guesses about the contents of a signal, using fractions—rather than ones or zeroes—to represent ambiguous data. Promising guesses are refined further, and only after several passes does the algorithm settle on a single interpretation.

Ascom is a year or two from a hardware implementation of its algorithm, but Mercury hopes to test its system with a telecommunications firm this year. Some insiders consider that hope optimistic: "Will there be applications for multiuser detection? Sure," says Paul Whalen, chief executive officer of Colchester, VT-based telecommunications training company Hill Associates. But he adds that right now, the technology "is in the domain of the researcher, and the apparent complexity of the solution may scare a lot of people." Nonetheless, Mercury vice president Barry Isenstein says the technology is ready to go: "At this point," he says, "we are not the limiting factor." Soon, the same could be true of cell towers. —*Larry Hardesty*



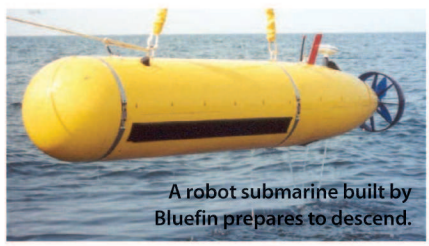
END OF THE TETHER

ROBOTICS | **Oil companies, navies and oceanographers are always trying to sharpen their picture of the ocean floor. Until now, they've relied largely on surveys performed by remotely operated vehicles, tethered by cables to ships. But the tethers restrict how deep and fast the unmanned vehicles can go. Now, thanks to advances in artificial intelligence, a few companies are building completely cable-free autonomous underwater vehicles that can gather data on explosive mines or new offshore oil-drilling sites faster and more cheaply than remotely operated vehicles.**

Several large manufacturers, including Boeing, Lockheed Martin, Norway's Kongsberg Simrad and Denmark's Maridan make autonomous underwater vehicles. But despite the impressive competition, a startup based in Cambridge, MA, called Bluefin Robotics may be leading the pack. It has sold 16 robots to universities and the U.S. Department of Defense in the last three years and recently sold another to its first private-sector customer, an oil and gas survey company.

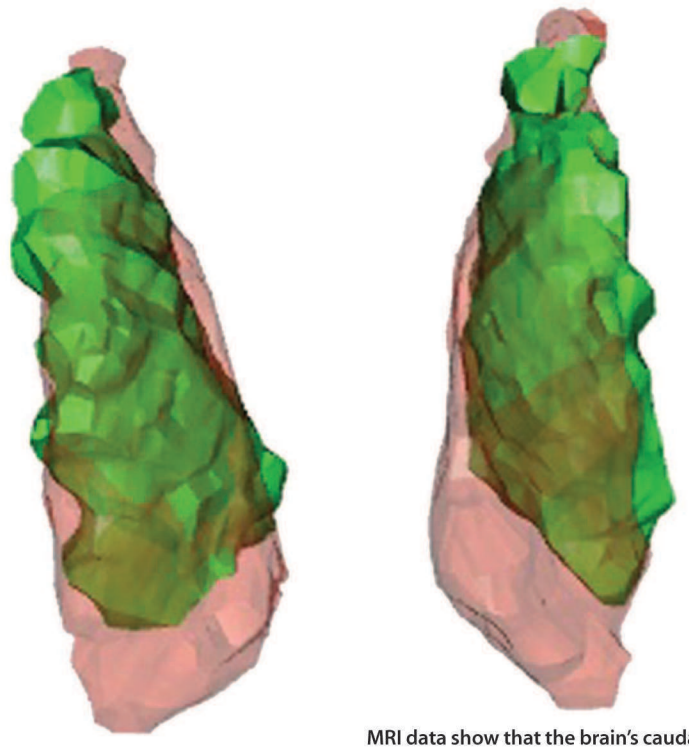
A three-meter-long Bluefin submarine is programmed with the latest in autonomous control systems. Bluefin engineers might define a square of ocean floor for the submarine to survey; low-level software would guide the craft back and forth across that area, directing it when to turn, while high-level safety and self-monitoring functions would enforce rules to protect the vehicle—for example, forbidding it to go within 10 meters of the ocean floor. The advantage is that Bluefin's customers can specify mission goals without having to anticipate every possible glitch, because the vehicle knows how to protect itself.

The Bluefin craft can't yet handle subtler tasks such as finding a pipeline and then following it. But given further advances in areas such as image recognition, says Roger Lott, head of surveying at BP, autonomous submarines have the potential to make underwater surveys "orders of magnitude" more efficient. —*Julie Claire Diop*



A robot submarine built by Bluefin prepares to descend.

COURTESY OF BLUEFIN (TETHER); JAMES YANG (ILLUSTRATION)



MRI data show that the brain's caudate nuclei are smaller in multiple-sclerosis patients (green) than in normal subjects (pink).

PRECISION BRAIN SCANS

High-tech imaging takes the guesswork out of diagnosis

MEDICINE | The main skill in diagnosing neurological disorders such as multiple sclerosis and Alzheimer's disease: educated guesswork. Indeed, today's doctors rely primarily on interviews, physical examination and laboratory tests to detect these complex neurological diseases; the problem is that symptoms can vary dramatically from one patient to the next, making diagnosis tricky and subjective. But by combining new databases with improved medical-imaging techniques able to resolve telltale anatomical features a millimeter in size or less, researchers are starting to make the invisible visible, potentially enabling them to offer patients earlier and more accurate diagnoses.

At the State University of New York at Buffalo, for example, researchers have developed software that renders three-dimensional pictures of the brain from magnetic-resonance imaging data, allowing them to digitally parcel off areas of the brain and precisely calculate their size and volume. Rohit Bakshi, director of the Buffalo Neuroimaging Analysis Center, has used the technology to show that the caudate nucleus—a part of the brain's gray matter involved in motor control and thinking—is significantly smaller in multiple-sclerosis patients than in healthy patients *(see image)*. Through such software tools, Bakshi hopes to standardize the way neurologists analyze MRIs. "Today, two clinicians can look at the same MRI and see it differently," says Bakshi. "We're working on making MRI a quantitative and standardized test, like a blood test, where you get a specific, reliable value back, and you can accurately compare the results to normal people."

"Today, two clinicians can look at the same MRI and see it differently. We're working on making MRI a quantitative test where you get a specific, reliable value back."

Besides aiding diagnosis, the new techniques could help track the course of a disease—and the benefits of treatments. Bruce Rosen, director of the Martinos Center for Biomedical Imaging at the Massachusetts General Hospital in Boston, and his colleagues are already using MRI machines to measure the thickness of brain structures only one-tenth to two-tenths of a millimeter in size. "That means we could see changes in the brain in response to a drug that occur in three to six months instead of assessing memory improvements, which tend to evolve over 12 to 18 months," says Rosen.

To help standardize the diagnosis process, Bakshi's center is developing a large database of brain scans taken from multiple sites across the state of New York. With more than a thousand images already in stock, he and his colleagues are building software that correlates scans of multiple-sclerosis patients with data about the courses the disease takes with them, to identify variations and predict whether patients will recover or develop chronic illness. A consortium of U.S. universities, which includes Rosen's imaging center, started work this year on a similar database network containing brain scans of Alzheimer's patients from across the country. The $20 million project will connect databases at hospitals and universities in California, North Carolina and Massachusetts. "Ultimately, our hope is that when somebody comes in and we take a brain scan, we can make a diagnosis, stratify their disease and determine what treatments would be most effective," says Rosen.

"Databases like these are definitely the future," says Robert Knowlton, a neurologist at the University of Alabama at Birmingham Hospital. Better classifications of brain diseases, he says, will ultimately lead to better treatments. —*Alexandra Stikeman*

COURTESY OF ROHIT BAKSHI

CARGO: KIDNEY

A futuristic cooler could get organs to those in need



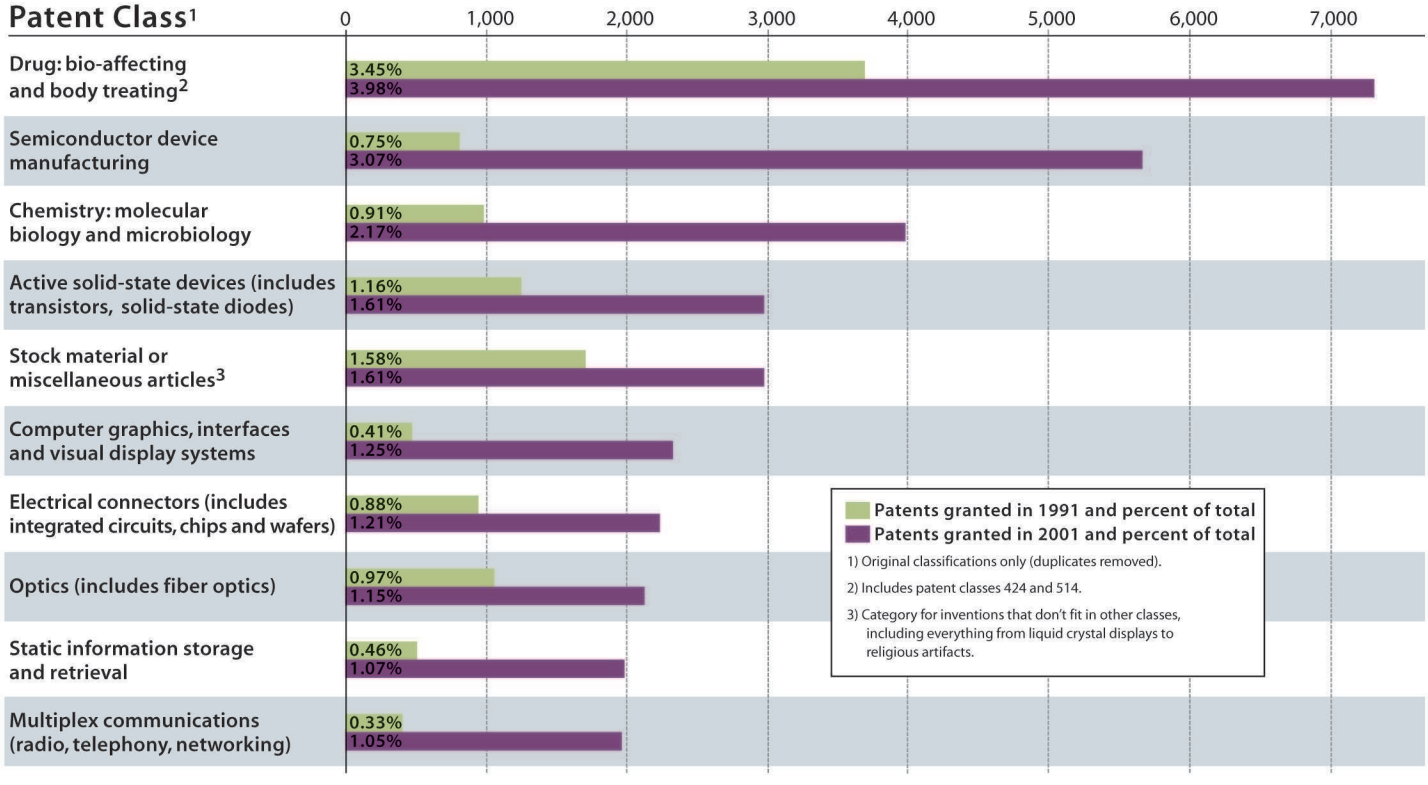
MEDICINE | Organ donation rates are rising in the United States, but they haven't kept up with demand. More than 50,000 people are awaiting kidney transplants alone, according to the United Network for Organ Sharing. One reason for the shortage is the difficulty in transporting donated organs to where they are needed. Because of the primitive way organs like kidneys are currently shipped—in plastic containers filled with ice and suspension fluid—they can remain only viable for about 20 hours.

Enter an experimental container designed by Des Plaines, IL-based Organ Recovery Systems to keep life-giving fluids circulating through donated kidneys even during long-distance trips. The portable device approximates the treatment organs receive at the company's perfusion centers in Chicago and Baltimore. A kidney "admitted" to one of these centers is attached to a machine that pumps solutions containing various salts, nutrients and medicines through its blood vessels; technicians monitor the fluid flow, pressure, acidity and other factors inside the organ until it's healthy enough for transplantation. The new transport vessel contains "all the necessary components" for treatment except certain chemical solutions that surgeons must add, says company chief executive officer David Kravitz. Tests on animal organs, he says, show that perfusing a kidney during transportation can keep it viable for up to 48 hours.

Approval from the U.S. Food and Drug Administration is expected sometime this fall, according to Kravitz, and similar units for the heart, liver and pancreas are in the works. The company's work has opened up an "opportunity for considerable advances" in organ transplantation, says Stephen Jensik, associate director of renal transplant programs at Rush Presbyterian Saint Luke's Medical Center in Chicago. If Jensik is right and the technology takes hold, more patients than ever before may be receiving a life-saving special delivery. —*Miriam Boon*

TEN TRENDSETTING TECHNOLOGIES

PATENTS | **Many of the most commercially active technology fields today, as measured by patent activity, were barely on the map a decade ago. Here's a look at the top 10 technology classes to which the U.S. Patent and Trademark Office assigned new inventions in 2001, with a comparison to activity in these same areas in 1991.**



SOURCE: U.S. PATENT AND TRADEMARK OFFICE; COURTESY OF ORGAN RECOVERY SYSTEMS (KIDNEY)

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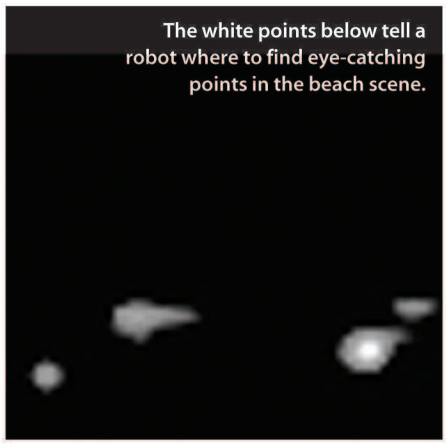
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The white points below tell a robot where to find eye-catching points in the beach scene.

COURTESY OF LAURENT ITTI

ROBOTIC VISION

Neuroscience-based strategies give robots a new outlook

There are some sights and noises that people just can't help but notice. Indeed, research in neuroscience now suggests that the recognition of salient objects is a key part of how we make sense of our environment. But building robots that can intelligently pick out items of interest using sight or sound remains a daunting challenge. So a handful of engineers are working on a new approach called selective-attention modeling, which attempts to program robots to evaluate scenes critically as some neuroscientists believe people do.

"General scene understanding is the Holy Grail for computer vision," says University of Southern California computer scientist Laurent Itti. Neuroscience-based algorithms, he contends, "should be the new approach."

Several research groups, including ones at Caltech and Itti's lab at the USC, are giving robots pan-and-tilt cameras for eyes and the ability to pick out unusual objects. The robots are designed to notice, for example, a bright purple tree house at the side of a wooded road and to do it for the same reason people would—because it stands out against a backdrop of trees. Responding to eye-catching sights enables robots to act independently when they encounter something unexpected. A robot on Mars, for example, might notice an area of the ground that is discolored and take a sample of it. In contrast, robots using more traditional vision methods would detect the discolored ground only if they had been told specifically to look for it.

Itti's robots construct maps on the basis of such local contrasts in features as color, edges, orientation, light intensity and motion. The tree house would stand out on the orientation map because of its horizontal profile amidst the vertical trees. It would also be conspicuous on the color map. The robot would overlay these maps to build a composite that highlights any striking areas.

This technique works basically the way your brain does when you scan a "what's wrong with this picture" type of puzzle. But robotic vision needs to do more than just pick out anomalous sights. So Itti and others, such as Caltech's Christof Koch, are also programming robots to use the approach to find specific objects. A robot looking for that purple tree house, say, knows to put greater weight on purple objects in its color map. And when forming the composite map, it will give greater weight to the color map than to other maps; the motion map, for instance, would be irrelevant, since both the tree house and its background are mainly stationary.

The strategy differs from conventional approaches to robotic vision. One common method, for example, is called object segmentation. To learn to find a coffee cup, a robot first examines a picture of the cup. It extracts—or segments—the cup's image out of the picture. Next, it erases anything that occludes the cup, say, a sugar bowl, and cleans up the image, maybe creating a black silhouette of the cup on a white background. The robot then estimates what the cup looks like at different scales and rotations. Only then can it conduct its search—homing in on objects that have shapes similar to the cup's, until it finds a match.

But using object segmentation can be cumbersome, and it's not especially reliable, says Polly Pook, vice president for research at iRobot, a robotics developer in Somerville, MA. She is impressed with the selective-attention models Itti and others are building. "I think it's a great approach," says Pook. "It's simplifying the process."

Visual selective-attention models, however, still have many shortcomings. Itti's robots cannot tell the difference between a black laptop and a neatly folded black turtleneck, for example, since their software has no way of knowing the difference between metal and fabric. But engineers hope texture maps will one day advance visual selective-attention processing yet another step, so robots can make such distinctions.

Researchers are also thinking about incorporating data from other senses, such as touch, into the final map, although they're not yet sure how this can be done. Any robot that interacts with its environment will benefit from having tactile senses, says Ernst Niebur, a neuroscientist at the Johns Hopkins University. Niebur feels confident that he can build a tactile map that would then feed into the final composite map. "We know the brain is capable of doing it," he says.

The next leap is putting the robots in the field. Finding a purple tree house is small stuff compared with navigating a crowded street. That takes a robot that can quickly process and respond to multiple stimuli. But just knowing where to look and what to look out for is at least a small robotic step forward.
—Julie Claire Diop


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AN RFID BILL OF RIGHTS

Think of it as a bar code for your bra.

Tiny wireless identification tags are soon going to start showing up throughout your daily life. If you have an E-ZPass transponder in your car or one of several Swatch watches on your wrist, you're already carrying a wireless tag. Your house, your food and even your clothes might someday be permeated with such tags, which can be read without your permission or knowledge.

Think I'm crazy? Last November, Texas Instruments and the Gap announced that they had completed a three-month test in which every piece of denim in a store in Atlanta received a wireless ID tag. This technology, boasts TI, allows each item of clothing to be tracked from the warehouse to the shelf to the checkout counter. Some of the largest retailers and consumer products firms, including Coca-Cola, Home Depot, Procter and Gamble and Wal-Mart, have joined to create standards to make sure that future tags and readers will all be compatible. That work is being done at the MIT-based Auto-ID Center.



By themselves, these tags seem harmless enough. Hit one with a radio beam at the right frequency, and it spurts out its unique serial number; that's why they're known as radio frequency identification (RFID) tags. E-ZPass uses the serial number to debit a driver's account when he or she passes through a tollbooth; companies like the Gap and Coca-Cola will use it to track inventory. Many animal shelters now have devices to look for tags implanted in lost household pets, speeding their return to their owners. Ranchers track cattle by implanting tags in the animals' ears. Futurists say that one day we might have houses filled with RFID readers and use them to find lost glasses, key chains and other tagged items.

The first mass application for these radio-read tags, however, will be inventory management and control. Playtex might put a tag in each bra to make sure that shipments destined for Asia aren't diverted to New York, where consumers are likely to pay more. Pass a reader over a box of bras and every undergarment will sing back its serial number. This allows for more accurate inventory control than tracking boxes does; individually serialized garments also make it dramatically harder for corrupt employees at a warehouse or trucking company to make a few bras "disappear," since automated readers will continually log the whereabouts of every item.

To increase public acceptance, the companies backing wireless ID systems are touting potential consumer benefits. A reader built into your washing machine, for instance, might automatically warn you that the dyes in your red shorts aren't colorfast and will ruin your yellow blouse. Microwave ovens might read the tags in frozen-dinner packages and automatically calibrate to cook your food properly. Already under development is tag-embedded meat packaging, which could help trace the spread of *E. coli* and other food-borne contaminants.

But it's easy to see how this technology could be misused. A woman I met at a privacy conference told me she didn't want a man standing next to her to be able to learn the make and size of her bra using a handheld reader hidden in his pocket. (Such readers already exist.) Others fear that implanted chips might one day be required for people, the way some cities now require them for pets. Some nursing homes are already giving their patients RFID bracelets; in Florida this past May, a family and, separately, an 82-year-old man voluntarily had the chips implanted to help identify them in case of emergency.

The likely proliferation of these devices has spurred me to come up with this RFID Bill of Rights. Consumers should have

- The right to know whether products contain RFID tags.
- The right to have RFID tags removed or deactivated when they purchase products.
- The right to use RFID-enabled services without RFID tags.

Your house, your food and even your clothes might someday be permeated with wireless ID tags, which can be read without your permission. It's easy to see how this technology could be misused.

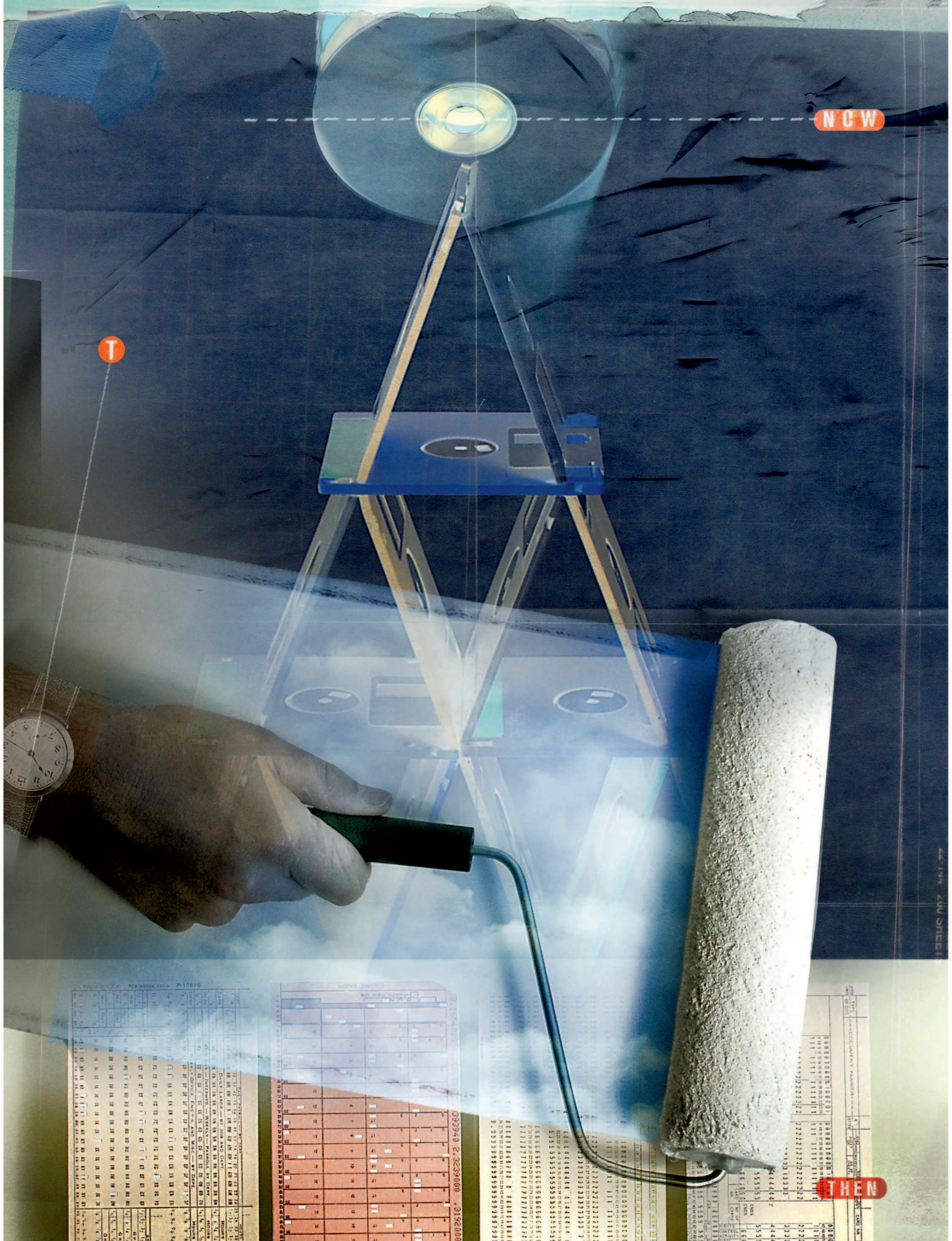
- The right to access an RFID tag's stored data.
- The right to know when, where and why the tags are being read.

I see these not necessarily as the basis for new law, but as a framework for voluntary guidelines that companies wishing to deploy this technology can publicly adopt. Consumers could then boycott companies that violate these principles.

Of course, some of these "rights" could easily be curbed or otherwise limited by federal regulation. For example, the U.S. Department of Transportation could require certain safety-critical parts inside a car to have radio tags to aid in recalls. But for the overwhelming majority of applications, these rights make sense. Manufacturers have no business playing hide-and-seek with radio tags when consumer privacy is at issue. Likewise, they shouldn't be able to require that consumers choose between participating in tomorrow's economy and preserving their privacy. For example, this spring the Massachusetts Turnpike Authority started giving discounts to state residents who pay tolls with electronic transponders—a policy that is both discriminatory and coercive.

RFID is moving slowly enough that we citizens can still influence the way it will be deployed. But we will lose this chance if we do not make our voices heard soon.

Editor's note: Simson Garfinkel, now a graduate student at MIT, plans to work with the Auto-ID center on privacy issues.

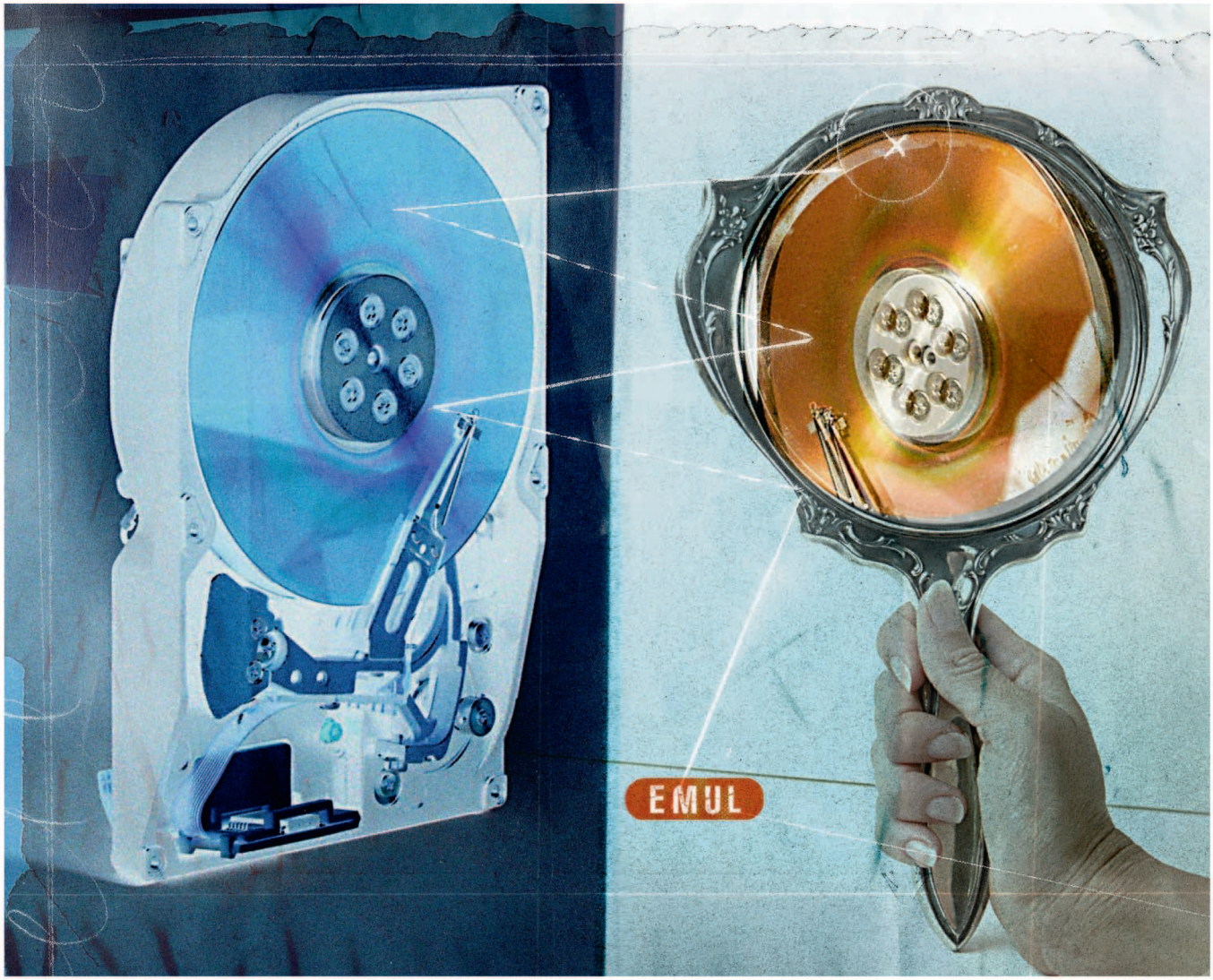

NOW
THEN

ALL RECORD OF OUR ELECTRONIC AGE COULD BE ERASED—UNLESS WE LISTEN TO THE NEW DIGITAL PRESERVATIONISTS.

DATA EXTINCTION

IN 1988 KEITH FEINSTEIN BOUGHT A STAR WARS ARCADE GAME FOR HIS COLLEGE DORM ROOM. Besides keeping him in beer and pizza money for the next four years, it also launched him on a personal journey that has lasted into the present: he now owns more than 900 vintage video arcade games, which he exhibits in a traveling show known as Videotopia. "People cry," says Feinstein, who is now 34, and who remembers a childhood complete with the earliest Pong console and an Atari 2600 he loved. "They can walk into an exhibit with hundreds of machines, and in all that incredible cacophony, they run right to *their* game. These games were a part of our lives. They were our first interactive media." Some of Feinstein's lovingly preserved devices are probably the last working models on the planet—the only machines where the 20-year-old software behind these games can come alive on the hardware it was meant for.

BY CLAIRE TRISTRAM • ILLUSTRATIONS BY STUART BRADFORD



Just about the time Feinstein bought his first arcade game, Abby Smith was completing a PhD in medieval Russian history at Harvard University. She was troubled, though, that only a handful of writings from before the 14th century—mostly liturgical documents—had survived the tumult of Russian history. How much had been irretrievably lost? How much of her own time was going to be lost to the future? Something about those questions struck Smith as far more interesting than the work she was doing, so she threw over Russian history to specialize instead in library science. For the past two decades, Smith has helped the U.S. Library of Congress in its task of preserving history. At first she occupied herself with such tasks as saving Lincoln's original Gettysburg address from deterioration, but as our culture has grown more digital, Smith has in turn become ever more focused on solving the problem of preserving digital artifacts. She is currently director of programs at the Council on Library and Information Resources, a Washington, DC, nonprofit organization that's helping the Library of Congress draft a proposal asking legislators to fund research on a long-term solution. "The layman's view is that digital information is more secure, when in fact it's far more ephemeral," she says. "We know how to keep paper intact for hundreds of years. But digital information is all in code. Without access to that code, it's lost."

Smith and Feinstein are working opposite ends of the same problem: how to preserve digital things—data, software and the electronics needed to read them—as they age. Paper documents last for hundreds of years, but more and more of what matters to us is digitally produced, and we can't guarantee that any of it will be usable 100, or 10, or even five years from now. Feinstein's contribution toward staving off digital obsolescence is to scour flea markets for old circuit boards that might have the chips he needs to repair old games; he is obsessed with keeping every game in his collection working. Smith's approach is to develop a plan for preserving culture itself; she is obsessed with guaranteeing, for example, that 300 years from now, people will be able to read files that locate nuclear-waste sites. Both are faced with the knowledge that current methods for preserving digital things work poorly, even in the short term.

Just how bad is the problem? Examples of digital things lost forever abound, some personal in scale, some global. Software patents that can be infringed freely because the original software no longer works, preventing the patent holders from proving prior art. Land use and natural-resource inventories for the State of New York compiled in the late 1960s that can't be accessed because the customized software needed to open the files no longer exists. NASA satellite data from the 1970s

that might have helped us understand global warming, were they not unreadable today.

But far worse is yet to come. "Once you begin to understand what's going on at a more technical level," says Smith, "you realize that what's lost could be catastrophic." We can count on paper documents to last 500 years or longer, barring fire, flood or acts of God. But digital things, be they documents, photographs or video, are all created in a language meant for a specific piece of hardware; and neither computer languages nor machines age well. The amount of material at risk is exploding: the volume of business-related e-mail is expected to rise from 2.6 trillion messages per year in 2001 to 5.9 trillion by 2005, according to IDC, an information technology analysis firm. Maybe most of those messages deserve to be rendered unreadable, but critical documents and correspondence from government and private institutions are in just as much danger of digital obsolescence as spam.

Then there are databases, and software, and images, all of which are in a constant state of change: JPEG, for example, the standard many digital-camera users rely on to store family photos, is already in the process of being outmoded by JPEG 2000, a higher-quality compression standard. "Unless we do something drastic," says Margaret Hedstrom, professor of information at the University of Michigan's School of Information, "in one or two or five years it's going to be very difficult for people to look back and see the photos they took."

Proposed solutions include *migration*, which consists of updating or sometimes entirely rewriting old files to run on new hardware; *emulation*, a way of mimicking older hardware so that old software and files don't have to be rewritten in order to run on new machines; and more recently, *encapsulation*, a way of wrapping an electronic document in a digital envelope that explains, in simple terms, how to re-create the software, hardware or operating systems needed to decode what's inside.

All three solutions, however, have the same sticky problem: the fixes themselves are time-bound, able to work only for several years, or perhaps a few decades, before another fix needs to be made. They also require us to act now to preserve what we *think* might be important to the future. "We have the problem of how to preserve digital media—hard enough to solve—and we have the additional, impossible responsibility of deciding what to save," says Smith. "Nothing will be preserved by accident."

A newly proposed solution, ironically enough, might make use of a very old technology: paper itself. Not to preserve all the digital documents we are creating in hard copy, but rather to preserve the specifications for a decoding mechanism—a kind of "universal computer" defined by a few hundred lines of software code—that will allow the documents to be deciphered in the future. Archived on paper and across the Internet, the mechanism would be guaranteed to survive for centuries. Proponents of such an approach say it will make it possible to preserve *everything*—a complete record of humanity. Maybe then history can finally stop repeating itself.

WHAT'S SO HARD ABOUT DIGITAL PRESERVATION?

The naive view of digital preservation is that it's merely a question of moving things periodically onto new storage media, of making sure you copy your files from eight-inch floppy disks to five-and-a-quarter, to three-and-a-half, to CD, and on to the next thing before the old format fades away completely. But moving bits is easy. The problem is that the decoding programs that translate the bits are usually junk within five years, while the languages and operating systems they use are in a state of constant change.

Every piece of software, and every data file, is at its heart written to instruct a given piece of hardware to perform certain tasks. In other words, it is written in the language of a machine, not of humans. Whenever you create a digital thing, be it a document, a database, a program, an image or a piece of music, it is stored in a form that you can't read. "It's like it was written in invisible ink," says Jeff Rothenberg, a researcher at Rand, a think tank in Santa Monica, CA. "As soon as it's stored it disappears from human eyes, and you need the right resources to render it visible again, just like invisible ink needs some sort of solvent to be read." Yet rebuilding old hardware or keeping it around forever to interpret nearly extinct software or formats is economically prohibitive: when shippers dropped one of Feinstein's vintage arcade games, shattering it, its original manufacturer calculated the insurance costs to restore the cabinet alone at $150,000, while making new chips for the game—from dies that no longer exist—would have cost millions.

"WE KNOW HOW TO KEEP PAPER INTACT FOR HUNDREDS OF **YEARS. BUT DIGITAL INFORMATION IS ALL IN CODE. WITHOUT ACCESS** TO THAT CODE, IT'S LOST."

Software companies confront the problem of digital preservation every day as they update their code, making sure it works with the latest hardware and operating systems, while at the same time ensuring that customers can access old files for a reasonable amount of time. But without some sort of digital resuscitation, every application—from the original binary codes written in the 1940s to WordPerfect to the latest million-dollar database application—eventually stops working, and every data file eventually becomes unreadable. *Every* application and *every* file.

The evolution of operating systems—the programs that allow other programs to run—provides yet another challenge. As Microsoft improves Windows, for example, it introduces new guidelines for programmers, known as application programming interfaces every few months, adding some features and taking others away. In each new release, some interfaces are "deprecated," meaning that programmers are advised to stop using them in the software they write. But what does that mean for programs written before the change? Most programs

that use deprecated features will work for a while but they access the underlying architecture in a less direct way than the newer interfaces do, and the program is likely to run more slowly. How long before it stops? Most people actively trying to keep old files and applications opera-tional say that five years is pushing it. "Interfaces change continually," says one Windows developer. "It's like asking how often the beach changes shape. Sometimes big storms come and nothing looks the same."

But when programs are painstakingly rewritten to conform to new operating-system guidelines, they eventually become unable to access files created by their own precursors. "I frankly don't expect to have a version of Quicken in 10 years that will be able to read my tax files from today," says Gordon Bell, who led the development of some of the first minicomputers as vice president of research and development at Digital Equipment, and who now works as a senior researcher at Microsoft's Bay Area Research Center. "Especially anything that is database oriented, with a lot of complexity in the data structure, is difficult to move from one generation to the next."

MIGRATION: DIGITAL TRANSPLANT OPERATIONS

One of the most common methods for preserving digital information is migration, where the bits in a file or program are altered to make them readable by new hardware and operating systems. It's what happens when you open an old document, such as a Microsoft Word 95 file, with a new iteration of the same software, say Microsoft Office 2001. The drawbacks? Each file needs to be opened, converted and saved individually, a process that grows impossibly large when you consider a librarian's or archivist's initiative to save as much of the historical record as possible. And eventually even the most meticulous of software companies stops supporting old versions of its products. If a file has not been migrated before that time, it's digital gibberish.

Worse, each time a file is migrated, some information is irreversibly lost. "Imagine someone saying, 'Okay, the way we're going to preserve Rembrandt is that five years from now we're going to have another artist come in and copy his paintings, and then we'll throw away the original,'" says Rand's Rothenberg. "And so on after another five years. The notion is laughable with art, because you know that every time you copy, you corrupt. It's the same with computers."

Migrating text files is hard enough; migrating application software is even more so. Indeed, the term "migrating" is a misnomer, since it often means throwing out the old program and writing an entirely new one in a new programming language, a process that programmers prefer to call "porting." The new program may look the same on the monitor, but underneath it is new. No matter how carefully software engineers have worked to simulate the old program, every line of code is different, with new bugs and new idiosyncrasies.

In any case, it's rarely the goal of the new program to simulate the old one exactly; it's far more common for programmers to want to improve upon the past. That's a goal that keeps computer science advancing at an exponential rate, and it probably also explains why the technical problem of preserving the past has received so little attention from those who helped create the problem in the first place.

"Computer scientists are in a profession where there is virtually no need for historical information," says Abby Smith. "They don't need information from the 1650s or the 1940s. They are used to things superseding what came before. For those in the humanities, there is no such notion. They work by accumulation, not replacement."

EMULATION: DIGITAL CPR

An even purer example of the problems associated with preserving digital objects is seen in the widespread attempt to keep arcade games like Joust and Asteroids playable today. Feinstein is keeping old games alive by preserving the machines that run them, but many others are trying a different means: hacks are importing the games onto today's PCs.

Such hacks use a technique called emulation, creating a program that simulates the registers (storage locations in the central processing unit) and behaviors of the old machine, and which can fool old games into thinking they are being run on old hardware. Emulation has the advantage of keeping the original bits of a given file or program intact, warts and all. "In porting, it's difficult to capture the bugs and idiosyncrasies of the original," says Jeff Vavasour, chief technical offi-

Digital-Preservation Proposals

TECHNIQUE	DESCRIPTION	PROS	CONS
Migration	Periodically convert digital data to next-generation formats	Data are "fresh" and instantly accessible	Copies degrade from generation to generation
Emulation	Write software mimicking older hardware or software, tricking old programs into thinking they are running on their original platforms	Data don't need to be altered	Mimicking is seldom perfect; chains of emulators eventually break down
Encapsulation	Encase digital data in physical and software "wrappers," showing future users how to reconstruct them	Details of interpreting data are never separated from the data themselves	Must build new wrappers for every new format and software release; works poorly for nontextual data
Universal virtual computer	Archive paper copies of specifications for a simple, software-defined decoding machine; save all data in a format readable by the machine	Paper lasts for centuries; machine is not tied to specific hardware or software	Difficult to distill specifications into a brief paper document

cer of Emeryville, CA-based Digital Eclipse, which is currently writing software to revive the original Joust and other arcade classics. "In games, that's important. So we don't port. We use emulation instead."

Indeed, emulation has been proposed as a way to keep not just games but everything else digital alive. It has its own drawbacks, however. "Emulation doesn't preserve, it just mimics," says Feinstein. "The timing will be all wrong. Or the sound will be off.... It's like the guy who reshot the film *Psycho* using Hitchcock's shot book. You recognize something of the original, but mostly you recognize how different it is from the original."

Looking for hard evidence to support claims like Vavasour's, that emulation is better at preserving digital content's original look and feel, Hedstrom and his colleague Cliff Lampeso at the University of Michigan recently organized one of the first studies to compare migrated and emulated versions of the same software. Subjects first spent an hour learning the maze game Chuckie Egg on its original platform, the BBC Micro, a microcomputer popular in Britain in the mid-1980s. They then played the game twice more on modern PCs, once with a version that had been migrated into a modern computer language and again with the original BBC Micro code running inside an emulator. Hedstrom and Lampeso found no statistically significant difference in the way the subjects rated the performance of the two versions. Says Hedstrom, "It was not apparent that emulation did a better job."

"EMULATION DOESN'T PRESERVE, IT JUST MIMICS. IT'S LIKE THAT GUY WHO **RESHOT *PSYCHO*: YOU RECOGNIZE SOMETHING OF THE ORIGINAL, BUT** MOSTLY YOU NOTICE HOW DIFFERENT IT IS FROM THE ORIGINAL."

Nonetheless, some computer scientists have suggested "chains" of emulators as a temporary solution to the problem of digital obsolescence: as each generation of hardware grows obsolete, it will be replaced by a layer of emulation software. But it's an idea that has others shaking their heads. "It's extremely dangerous to talk about emulation as a solution," says David Bearman, president of Archives and Museum Informatics, a consulting group that works with business and government entities, helping them preserve digital files. "It gives an excuse to managers and governments around the world to put off doing things that really need to be done right now."

ENCAPSULATION: DIGITAL CRYONICS

Neither migration nor emulation, then, offers a satisfactory long-term way to wrest digital bits from what Shakespeare called "the wrackfull siege of batt'ring days." The only real way to keep digital things alive for the duration, many believe, is to lift them out of this inexorable march of digital progress—but to leave signposts that will tell future generations how to reconstruct what has passed.

Consortia of libraries and archivists worldwide are working on a solution called encapsulation: a way to group digital objects together with descriptive "wrappers" containing instructions for decoding their bits in the future. A wrapper would include both a physical outer layer, similar to the jacket of a floppy disk, imprinted with human-readable text describing the encapsulated content and how to use it, and a digital inner layer containing the specifications for the software, operating system and hardware needed to read the object itself. A Microsoft Word document, for example, might be packaged with instructions for re-creating Word, Windows and perhaps even an emulated version of a Wintel PC. For text documents, at least, encapsulation seems likely to be a viable method for long-term preservation, especially once international standards bodies agree on a uniform system for building wrappers. But if the documents being preserved contain more than simple text, encapsulation seems less likely to succeed: there are simply too many new software releases, compression schemes and hardware formats each year to describe all of them through encapsulation.

"The pagination is off even when you open a last-generation Word document," observes Steve Gilheany, senior systems engineer at Archive Builders, a Manhattan Beach, CA-based records-management consulting group that has assisted the city of Los Angeles in its digital-document preservation. "Imagine then what happens when you try to open it in a hundred years or try to access a digital object more complicated than pages of text."

Gilheany's proposed solution is simpler, borrowing the concept behind that archetypal decryption key, the Rosetta stone. He recommends archiving critical files in at least three formats: The first would be a standard raster or bit-map format, where there is a one-to-one correspondence between how coordinates are stored and how they are displayed, without the kind of compression used today for large files like JPEG images. The second would be the file's native format, whatever it happens to be, to simplify any future modifications. The third would be a "vector-based" format storing each letter, symbol or image in the form of a mathematical description of its shape on the page; Adobe Systems' Portable Document Format is one example. In theory, each version could be used to decode the others. Gilheany has spent eight years assisting the Los Angeles city government in converting its original infrastructure documents into raster and PDF files, and in the absence of a better solution, most government agencies and others with critical archival needs are taking a similar approach.

Encapsulation and conversion, though, require foresight; as Smith notes, anything that isn't expressly encapsulated or converted will surely disappear. These solutions also aren't particularly long lived, at least compared with things like stone hieroglyphs or even paper. "Some researchers predict very long lifetimes for some types of media," says Raymond Lorie, a research fellow at IBM's Almaden Research Center in San Jose, CA. "But if a medium is good for *N* years, what do we do for *N*-plus-one years? Whatever *N* is, the problem does not go away."

THE UNIVERSAL VIRTUAL COMPUTER

Proponents of emulation and encapsulation are thinking the wrong way, Lorie believes. Packaging complex data with the software needed to read it is too complicated, he thinks, and saving data in simple formats and trusting that someone a century hence will still be able to decode them is too risky. Instead, he's building a universal decoding machine—a primitive program that would begin working behind the scenes to preserve a digital thing as soon as it was created—and proposing that it be promulgated so widely that it would become an inextricable part of our culture, like copies of the Bible or the U.S. Constitution. This program would be written in a simple machine language; it could be used to unlock files and to run application software even after the formats in which the files are stored grow obsolete; and most important, it wouldn't require any particular foresight about which things should be saved.

Lorie believes that this program, which he calls the universal virtual computer, should be constructed independently of any existing hardware or software, so that it is independent, too, of time. It would simulate the same basic architecture that every computer has had since the beginning: memory, a sequence of registers, and rules for how to move information among them. Computer users could create and save digital files using the application software of their choice; when a digital file was saved, though, it would also be backed up in a file that could be read by the universal computer. When someone wanted to read the file in the future, only a single emulation layer—between the universal virtual computer and the computer of that time—would be needed to access it.

"Ray's suggested universal virtual computer is a good idea," comments Rand's Rothenberg. In fact, he says it's one possible version of a concept he has been developing himself, something called the "emulation virtual machine." Rothenberg's machine would be a universal platform for emulating obsolete computers, which could then run obsolete software to render obsolete digital objects. Lorie's solution, Rothenberg says, is similar in spirit but "far less general."

Lorie, however, believes in keeping things simple—so simple, in fact, that he wants to fit the specifications for his universal computer into only 10 to 20 pages of text, which could be distributed via the Web and copied out on paper everywhere, assuring their survival. "Saving one single paper document allows us to save millions of documents around the world," he says.

Will it work? Last September Lorie demonstrated his approach at the National Library of the Netherlands, successfully translating a PDF version of a scientific paper on drug research into his universal format. The reconstruction not only kept the look of the original's fonts and formatting, it also created "metadata" to clue in future users about its content.

In addition to text files, Lorie's approach could also be used to save today's digital photographs, sound and video files, and software applications for future generations; the content or software need only be described and saved in a way that is compatible with the universal computer. But he believes that the ability to decode today's data files will be far more valuable than the ability to run old software. Imagine, for example, being able to view data not just with today's visualization tools but in ways that won't be invented for another hundred years. "It's not just that you want to save the document," he explains. "You want to make the data within the document available to whatever new programs we may have in the future."

UNAWAKENED DEMAND

Boiling down the specifications for the universal virtual computer into a handful of pages poses technical problems that Lorie believes can be solved. But will they be? Like everything else involving information technology, they won't be until there is enough demand to pay for the development work. By that time, however, many digital things may be past the point of resuscitation. Lorie is the only researcher at IBM with funding to study the universal virtual computer. "I wish I could say I have 20 people working on the problem, but I don't," he says.

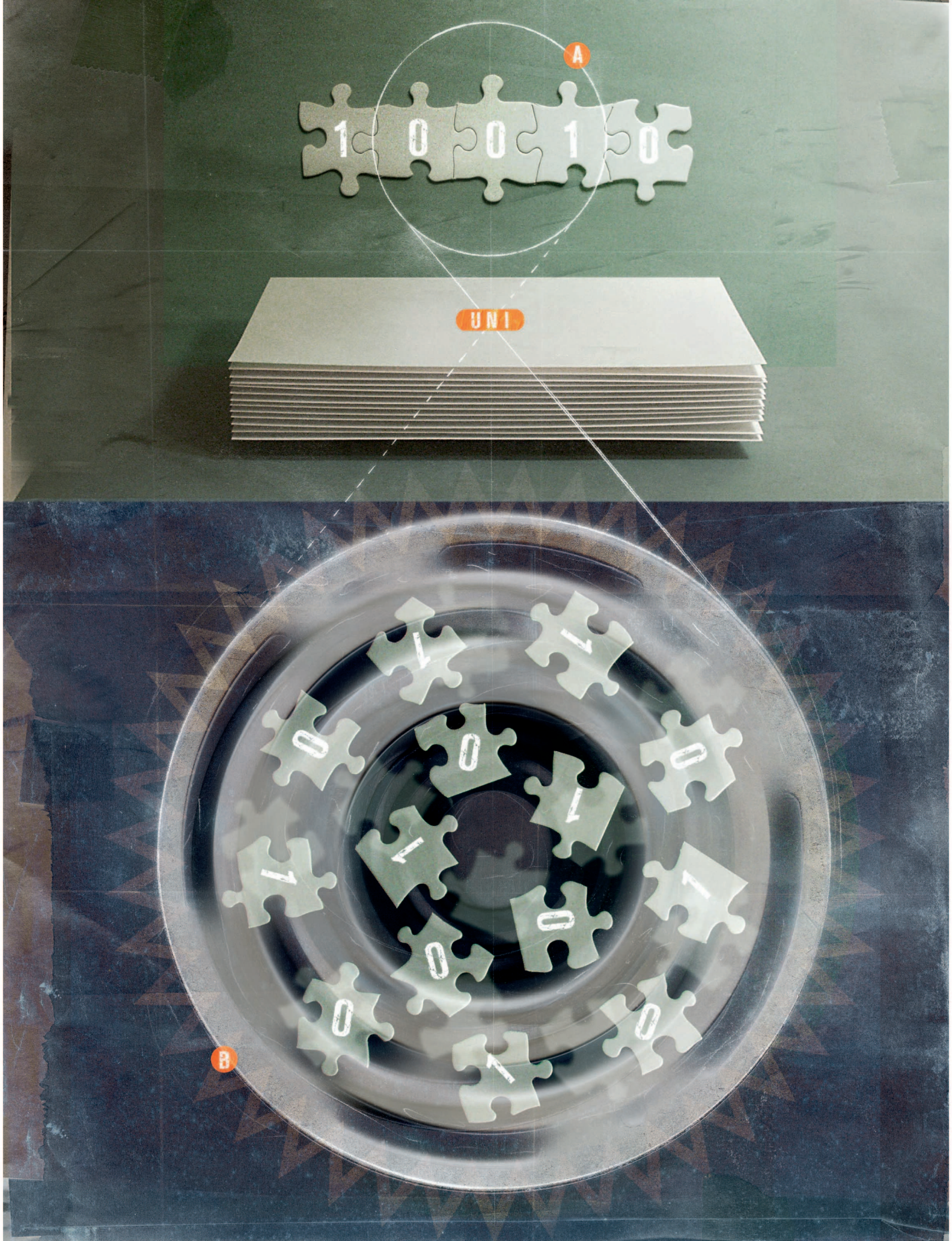
Robert Morris, director of the Almaden lab and Lorie's boss, doesn't equivocate. "It's unfortunate, but the reason there's not a huge amount of activity is because there isn't a lot of money in it," he says. "At the moment there are not a lot of people clamoring to solve this problem."

That may change as computer users realize how much has already evaporated. In October 2001 Brewster Kahle, the man behind a project known as the Internet Archive, put up a Web site known as the Wayback Machine, a way for people to search the archive's collection of 10 billion Web pages it had crawled over the previous five years. With 1997-era Web pages in his archive, Kahle is already grappling with preservation questions. Many of the pages suffer from broken links and half-missing text, and whole classes of items—those protected by passwords or payments, for example—aren't archived at all. "We don't know how much we've lost," he says.

Like global warming, the problem of digital preservation is so big that it's hard to grasp. But when a million people are using the Wayback Machine and not finding the digital files they're searching for? Then the problem starts to become real.

"People count on libraries to archive human creativity," Abby Smith says. "It's important for people to know, though, that libraries are at a loss about how to solve this problem." When computer users are saving documents or images, they don't think twice about making them accessible to future generations, she says. "They need to."

ARCHIVED ON PAPER, THE PLANS FOR A UNIVERSAL DECODING **MACHINE WOULD SURVIVE FOR CENTURIES, ALLOWING US TO SAVE** MILLIONS OF DOCUMENTS AROUND THE WORLD.


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Nanotechnology general: Edwin Thomas, director of the new Institute for Soldier Nanotechnologies, foresees materials breakthroughs.
PHOTOGRAPH BY KATHLEEN DOOHER

SUPER SOLDIERS

IF THE ARMY'S $50 MILLION INITIATIVE GOES ACCORDING TO PLAN, FUTURE SOLDIERS WILL SUIT UP IN UNIFORMS THAT, THANKS TO NANOTECHNOLOGY, GIVE THEM SUPER STRENGTH AND PROTECTION FROM BULLETS AND BIOWEAPONS. IT'S A FAR-OUT VISION, BUT KEY MATERIALS TO MAKE IT HAPPEN ARE ALREADY IN HAND. BY DAVID TALBOT



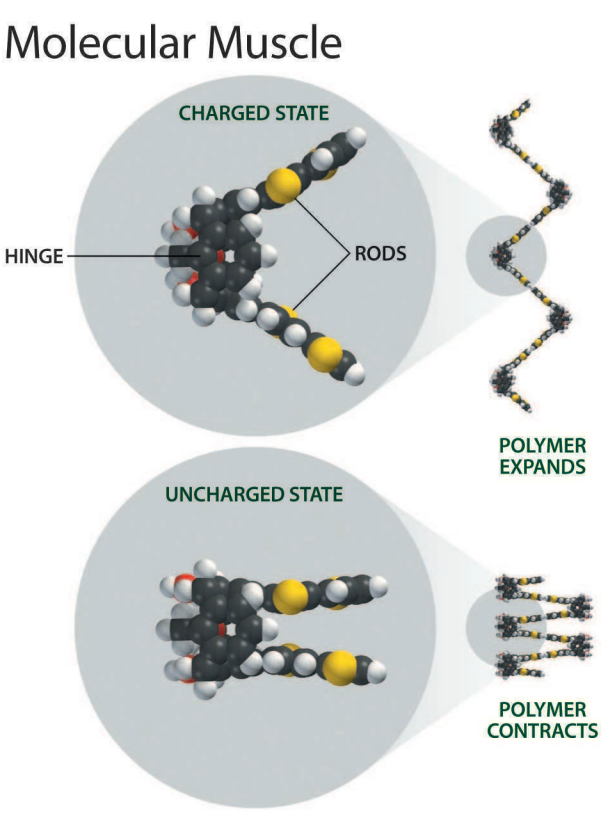
Late last year the U.S. Army went shopping for some new uniforms. It wasn't interested in camouflage jumpsuits and olive drabs or even in better versions of the high-tech gear worn by the troops in Afghanistan. What the army wanted was a lightweight combat uniform capable of stopping bullets and toxins, monitoring a soldier's health, communicating with remote commanders—even enabling superhuman strength. But despite the extravagance of that vision, and even though they were looking to academic research institutions for help, army officials made another key desire clear. As MIT materials scientist Edwin Thomas recalls, they "didn't want just papers in *Science* or *Nature*. They wanted real stuff."

Real stuff is exactly what MIT researchers presented last January to a visiting army team. Mechanical engineer Ian Hunter played a video of a twitching piece of black ribbon—an expanding and contracting "artificial muscle" that could, in a combat uniform, form a tourniquet or boost leg strength. Materials scientist Yoel Fink showed off some shimmering optical threads capable of reflecting and absorbing different wavelengths of light with great specificity—a property that could be exploited for remote infrared communication that might, for example, allow soldiers to silently identify themselves to allies at night. Faculty members explained the workings of a microscopic sensor MIT chemist Tim Swager had built, just a few molecules wide, that could sniff a soldier's breath for chemical signs of stress.

Six weeks after that presentation, MIT got the job—a five-year, $50 million contract to establish the Institute for Soldier Nanotechnologies, under Thomas's direction. MIT, industrial partners DuPont and Raytheon, and Boston's Massachusetts General and Brigham and Women's Hospitals collectively pledged an additional $30 million. As the institute's name implies, the army is pinning its ambitions on nanotechnologies—devices and materials that are engineered with features at the nanometer (billionths of a meter) scale. The power of this approach, in theory at least, is that controlling a material's smallest features will allow researchers to build an array of functions and protections into a simple, lightweight outfit.

The effort also provides a clear proving ground for nanotechnology at a time when funding for the young field is surging worldwide. In the United States, for instance, the new army institute is part of a national nanotechnology initiative that distributes about $700 million annually. But the new army initiative is "unique in the sense of the magnitude of the grant at a single university," says Richard W. Siegel, director of the Rensselaer Nanotechnology Center at the Rensselaer Polytechnic Institute in Troy, NY. Indeed, the army sees the new institute as a ripe opportunity to bring together disparate but rapidly maturing nanotechnologies. "The nation has been investing in nanoscience for 20 or so years," says Michael Andrews, the army's chief scientist. "It's time to start harvesting."

Even if it works—and that is still a big if—the high-tech fighting uniform will take time. The institute's five-year goal is to get the various functions ready and perhaps deployable as add-ons to existing military systems. Putting all the technologies together in one mass-producible garment could take a decade or more. Along the way, though, the effort could yield such nonmilitary advances as health-monitoring garments for the elderly, lighter bulletproof vests for police officers and new trauma-care gear for paramedics. "We have a mission: to make it safer for soldiers to do their job. But there will be spinoffs every which way," says Swager, who is associate director of the institute.



A polymer that contracts and expands as much as human muscle uses molecular "hinges" and "rods." The rods repel and attract one another when a charge is applied (top) and removed (bottom).

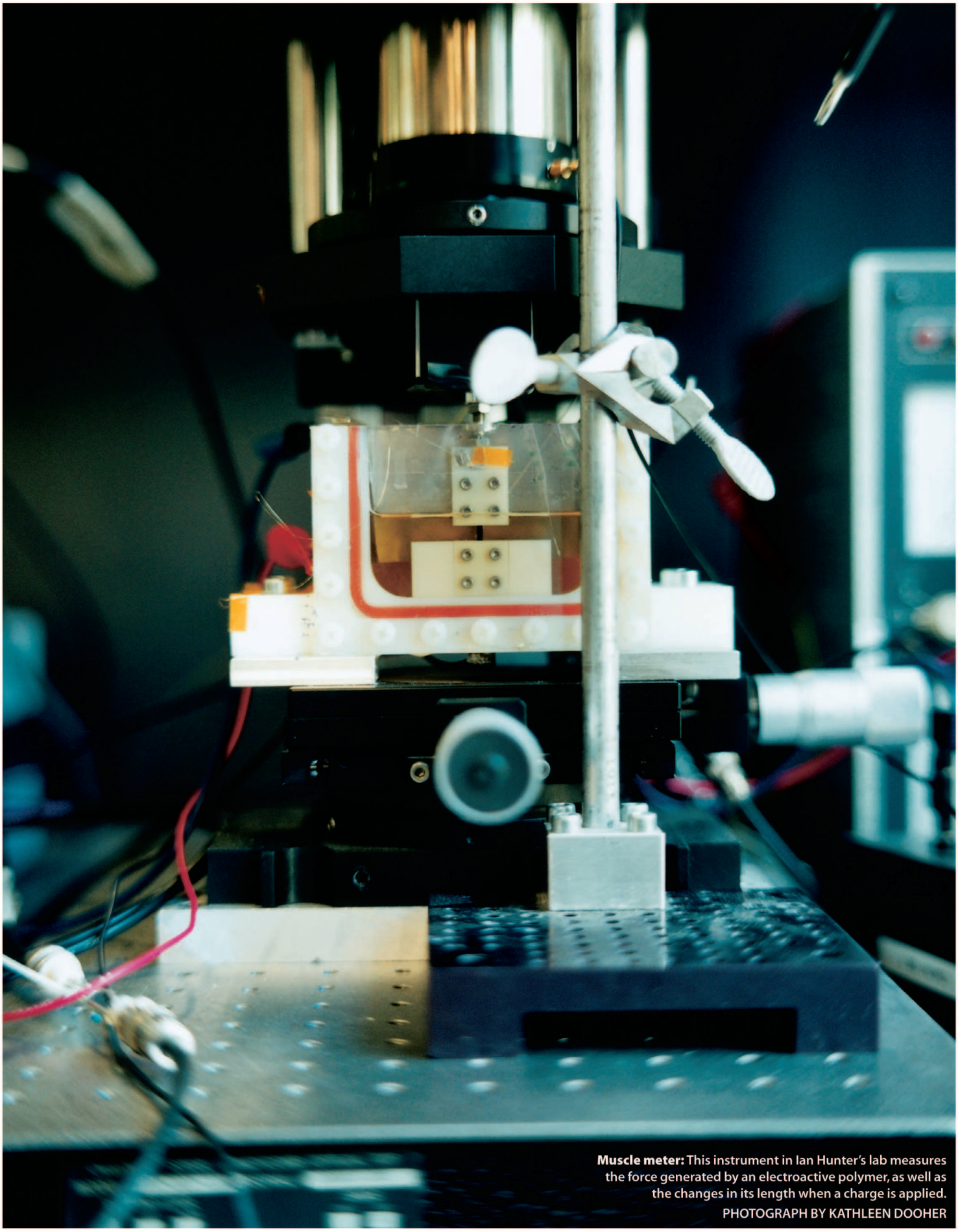
STRENGTH

A chief objective of the new institute is to create a combat uniform that has built-in strength—the strength to help a soldier lift heavy objects, to pump cooling fluids through embedded channels or to stiffen around a bleeding wound. Hunter's twitching black ribbon is an early indication that nano materials might be able to deliver that sort of strength.

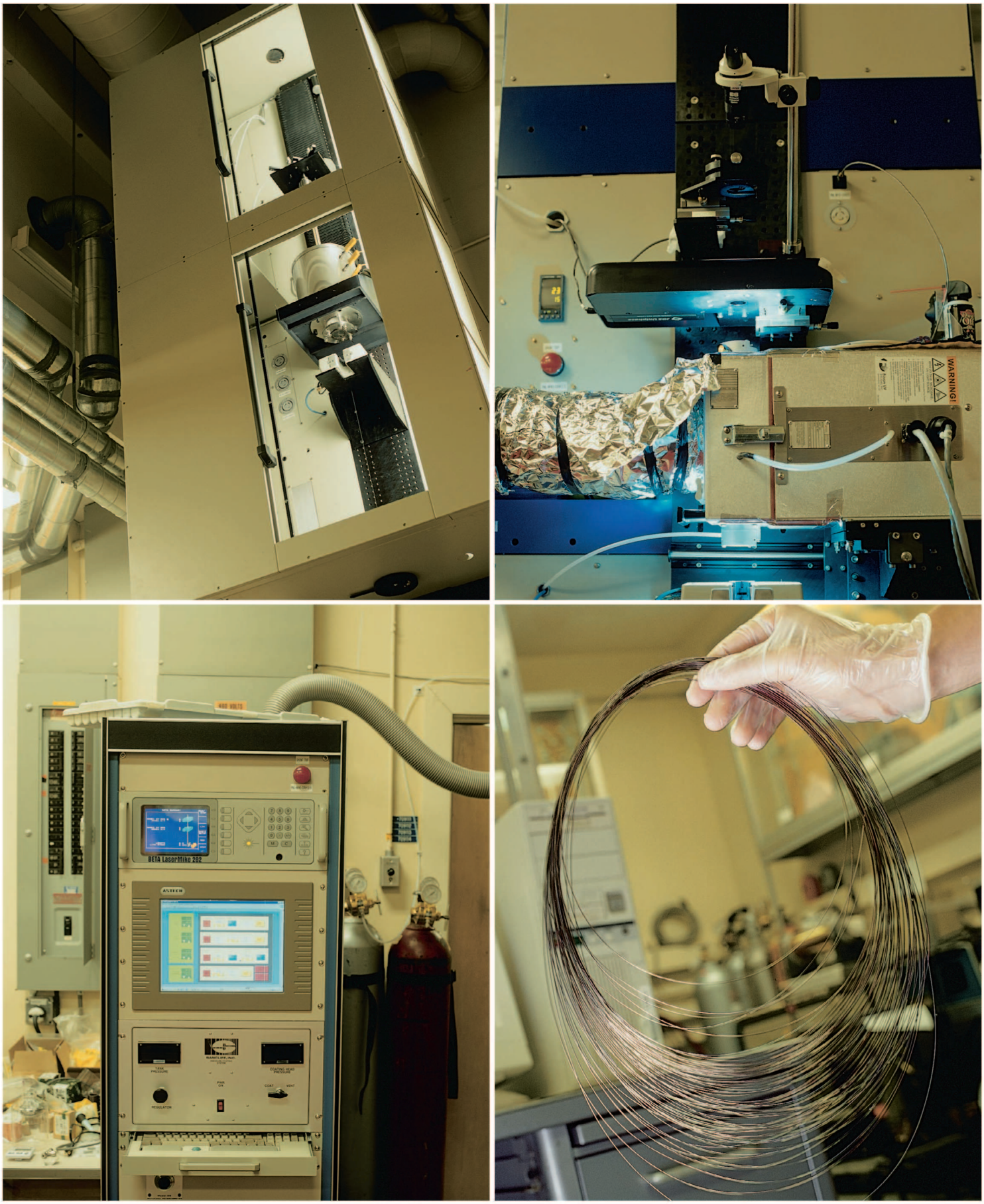
The ribbon is made of an electroactive polymer that can move or change shape in response to an electrical signal. Researchers have long envisioned using these polymers—which can be 100 times stronger than human muscle—as artificial muscles. But so far, they've proved impractical as musclelike machines, largely because their movements are relatively sluggish and also because they've been able to contract or expand by only a few percent of their length. Human muscle can contract and expand by 20 percent.

In Hunter's and Swager's labs, however, researchers have recently worked together to make great strides toward a material with enough range of motion to be useful. The key is a series of molecules that operate like rods and hinges. Pivoting on the hinges, the rods repel or attract one another when a charge is applied or removed. By attaching millions of these rods and hinges end to end like segments of a folding ruler, the researchers were able to create polymers that lengthen and shorten in response to electrical stimuli *(see "Molecular Muscle," this page).*

JOHN MACNEILL; SOURCE: MIT'S BIOINSTRUMENTATION LAB



Muscle meter: This instrument in Ian Hunter's lab measures the force generated by an electroactive polymer, as well as the changes in its length when a charge is applied.
PHOTOGRAPH BY KATHLEEN DOOHER



From rod to thread: In Yoel Fink's lab, centimeter-scale rods are thinned as they are pulled through a furnace known as a "draw tower" (top left and right). The process, which is monitored on a control unit (bottom left), produces optical threads just 400 micrometers in diameter (bottom right). PHOTOGRAPHS BY WEBB CHAPPELL

A film made of these polymers produces musclelike movements. "Within the last few months," says Hunter, "we've doubled the range of motion," approaching that of human muscle cells.

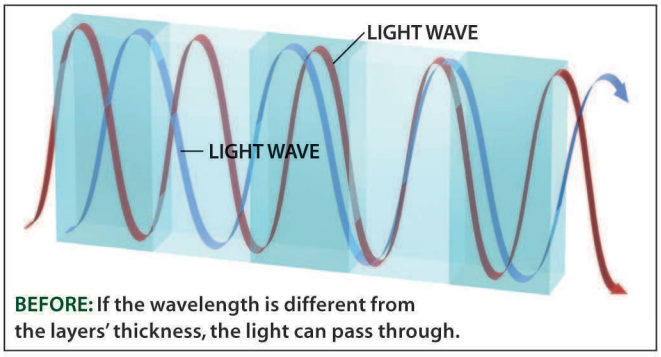
That increase in how much the polymer can expand and contract, combined with its impressive strength—which the researchers haven't measured yet but predict to be ten times that of human muscle—could conceivably allow a combat uniform embedded with 1.4 kilograms of the material to lift 80 kilograms one meter high. In other words, a soldier could effortlessly hoist a heavy piece of equipment or even a fallen comrade. The problem: this would take at least a minute, says John Madden, an electrical engineer at the University of British Columbia in Vancouver, who until recently headed electroactive-polymer research in Hunter's lab.

Giving these electroactive polymers useful speed is the next hurdle. It will require cutting back on the materials' electrical resistance, so an applied charge can do its work more rapidly. The researchers plan to reduce resistance by incorporating carbon nanotubes —long, pipelike molecules—into future generations of the materials. Certain versions of carbon nanotubes are excellent electrical conductors that could deliver charge throughout the material much more rapidly. The Hunter and Swager groups hope to make artificial muscles that are as fast as human muscle in five years.

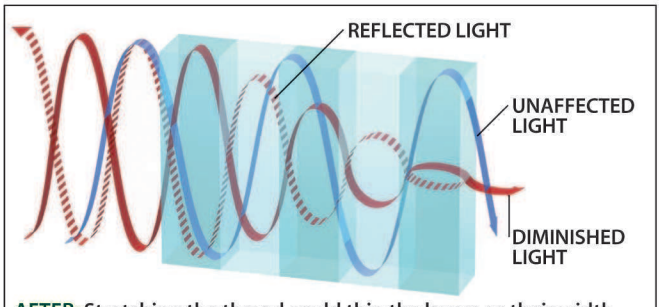
Integrating the muscle material with the rest of the soldier's suit is the larger challenge. The electroactive polymers need, for instance, to be wired into a power distribution and signaling system; conventional wiring is simply too rigid for the job of hooking up a twitching, flexing material. So in the past year, Hunter and his coworkers have developed ribbonlike wires made of flexible electrically conducting polymers. "Instead of stiff copper wires going into polymer 'tissue,' we will have tissuelike wires going into tissue," Hunter says.

Fine Tuning

A cross section shows the outer layers of optical materials coating a polymer thread. The layers' thickness determines how light is reflected.



BEFORE: If the wavelength is different from the layers' thickness, the light can pass through.



AFTER: Stretching the thread could thin the layers so their width matches the red wavelength. At each boundary between layers, some red light would be reflected (broken line), and some would continue on.

COMMUNICATION

Other technologies will be needed to allow the suit to communicate with the outside world. Earlier this year, MIT's Fink announced development of coated polymer threads that might be just the thing, enabling silent communication with remote allies or commanders through the use of visible or infrared light.

Fink's threads are able to selectively reflect or absorb different wavelengths of light, thanks to their coating, which incorporates numerous ultrathin layers of two transparent materials—one organic, the other inorganic. The two materials slow light at different rates. In the resulting riot of reflections within those layers, some wavelengths are strongly reflected back out of the fiber, and others are canceled out. Just which wavelengths get reflected depends on the thickness of the layers, which can range from 100 to 1,000 nanometers and can be precisely controlled.

While most photonics researchers are working on chips and other gadgets for optical telecommunications, Fink's group is the first to build a photonic thread that could be made into a textile, says Eli Yablonovitch, an electrical engineer at the University of California, Los Angeles, and a pioneer in optical materials. One possible use for these threads: a portion of a combat uniform that strongly reflects a specific signature of ambient infrared light. During the confusion of a nighttime firefight, for example, such an "optical bar code" could identify a soldier as friend to fellow troops equipped with night vision goggles tuned to the right reflected light. And Fink's team would also like to come up with a way of tuning these materials on the fly, so that the wavelength could be changed electrically (and remotely) in case an enemy got his hands on a uniform.

This presents a special challenge, Yablonovitch says. "There are many solutions. Just no good ones. They have their work cut out for them to make it practical for the army," he says.

For now, Fink's group is pushing ahead with several approaches to making the optical fibers tunable. One strategy involves creating a sort of stretching rack that could pull the fibers taut. The tension would thin the layers, changing the reflected wavelength *(see "Fine Tuning," this page)*. A second approach takes advantage of the fact that one of the materials in the layers—arsenic triselenide—slows light at a different rate in the presence of an electric field; change the field and you change the reflection of the whole fiber. These approaches, Fink says, could produce a tunable fiber within two years.

PROTECTION

Of course, the overarching job of the uniform is to protect the soldier, and the ability to jump from harm's way or to silently announce oneself to allies would do that indirectly. But the army's vision is of a suit that would also provide direct protection against everything from bullets to anthrax. Improved ballistic protection is mostly theoretical at this point, but some very real tools against biological and chemical attacks are already in hand.

JOHN MACNEILL; SOURCE: YOEL FINK

One such technology is based on highly branched polymer molecules called dendrimers. By modifying the ends of a dendrimer's branches so that each of them sticks to a dangerous molecule and renders it harmless, army researchers have already created a protective substance with great absorptive power for its weight. But so far, they've been able to use the substance only by mixing it into a sunblock-like cream. The problem with adding this technology to a soldier's suit is that dendrimers don't easily stick to each other and thus are difficult to form into a stable material that would stand up to the abuse of a battlefield—and a washing machine.

To help make a more rugged material, MIT chemical engineer Paula Hammond designed dendrimers with "tails." These tails, several times longer than the dendrimers' branches, tend to entangle with one another, keeping the molecules latched together without blocking the branches from doing their jobs. It's like an extensive root system for a forest of molecular trees, and it could allow the anchored dendrimers to make a tough protective film. "These technologies are just budding right now. We can take them and begin to incorporate them into fabrics and coatings," Hammond says.

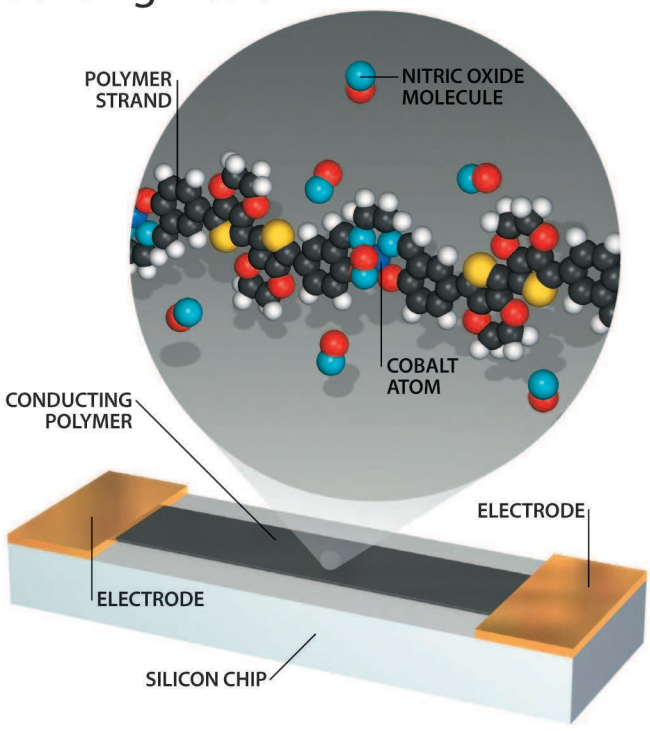
MIT researchers are also working on technologies that could help monitor a soldier's health remotely, regardless of what hazards he or she might encounter. Built-in sensors that detect changes in body chemistry, for example, might help determine whether a fallen soldier is critically wounded or can wait for aid. Such sensors would have to be extremely sensitive but also robust and simple to operate.

And Swager has made a good first step. Using specially designed polymers as the detector, Swager has recently developed a device to sense concentrations of nitric oxide, a chemical present in human breath. Nitric oxide spikes when the body is stressed *(see "Sensing Health," this page)*. Taken alone, a nitric oxide measurement might not tell the whole story, but the sensor "is a first element that could be part of ways of assessing the physiological state of the soldier," Swager says.

The nitric oxide detector uses nanoscopic polymer wires capable of conducting electricity. When nitric oxide binds to the polymer, it produces a change in electrical resistance that can be readily detected. Additionally, the nitric oxide molecules quickly fall off the sensor, giving the device the ability to provide continuous measurements of the chemical's concentration.

Although just a prototype today, Swager's device could eventually be incorporated into a mask or the fabric of a soldier's suit to detect other chemicals—such as hydrocarbons and ketones—that can be indicators of stress or disease, or to detect biological and chemical agents.

Sensing Health



A sensor that uses an electrically conducting polymer could directly detect nitric oxide concentrations in a soldier's breath. Cobalt atoms in the polymer bind and release nitric oxide molecules, causing fluctuations in the resistance of the polymer, which lies between electrodes.

INTEGRATION

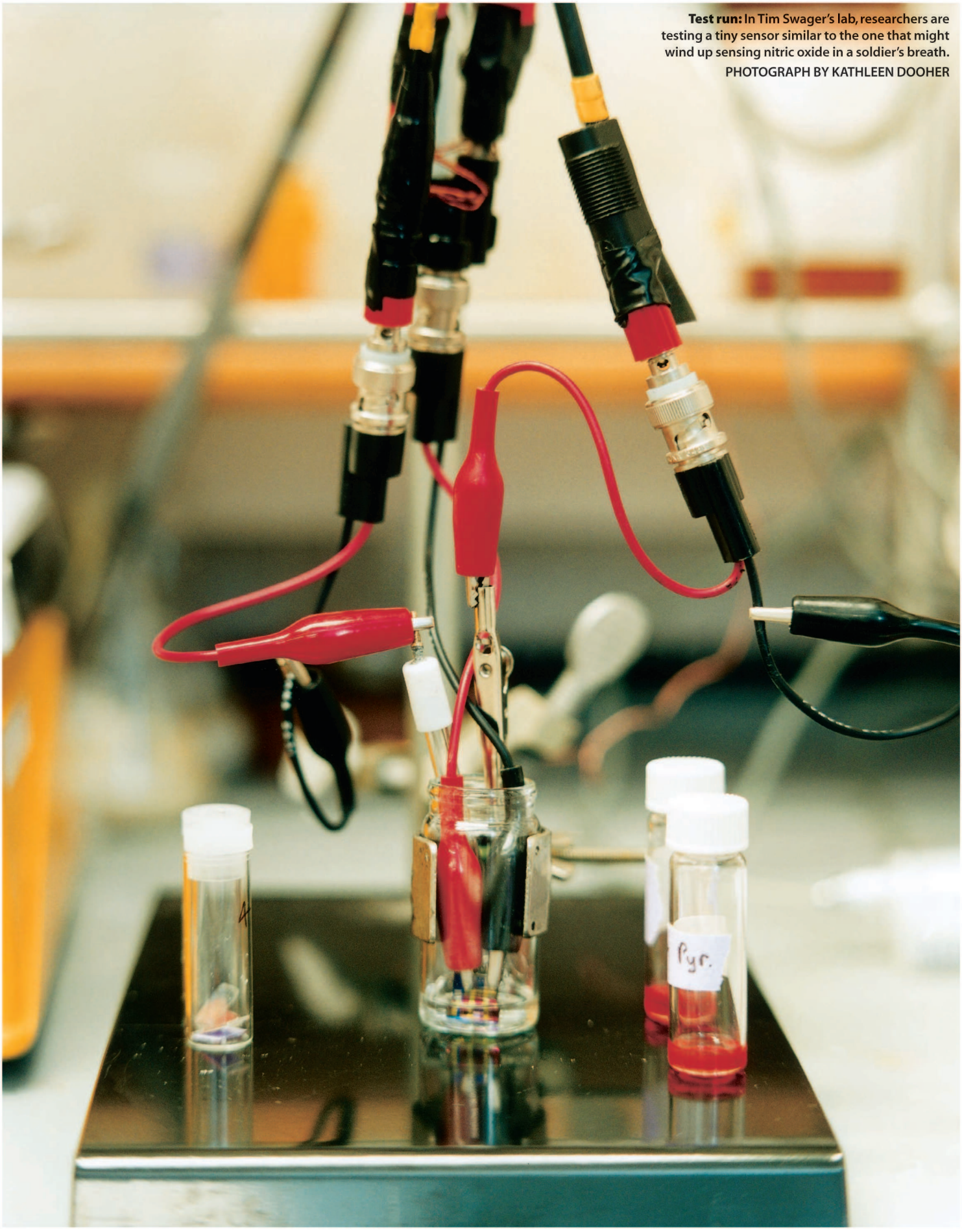
Even as Swager and the other researchers in the institute continue to churn out such new materials and devices, they are already thinking about what will ultimately be their biggest challenge: making all their inventions work together in a mass-producible suit. "It will be a systems and integration problem that we've never seen before," Swager says.

That's where DuPont could help. The company has decades of experience developing such ultrastrong materials as Kevlar, used for bulletproof vests. Now it will help create new processes for integrating several nano materials into one textile. One problem: not all polymers are compatible. "They are not the same, and they don't behave the same," says Wayne Marsh, research manager at DuPont Central Research and Development in Wilmington, DE. "Some are made very differently; the same process could degrade one polymer while forming another." Reconciling these differences will require tweaking the polymers' chemistry or adding coatings to protect them from one another. All in all, "this is really 'edge' stuff," Thomas says. "It's like Jack Kilby of Texas Instruments in the early 1950s, thinking about making just tens or hundreds of transistors on a single silicon chip. You have to say, 'How would we do that?'"

Army brass and the civilian medical community have high hopes that Thomas and his MIT colleagues will find the answer, figuring out not only how to perfect new materials and devices, but also how to weave them together with revolutionary results. But they're realistic. "I don't know that all of this is going to yield what I want, when I want it, and do it at an affordable price," the army's Andrews says.

For sure, the new institute won't produce the full integrated combat uniform in five years. Instead, success on that time scale will mean a much lighter bullet-resistant vest or rugged "friend-or-foe" optical material, says Thomas. "One measure of success will be if we have gotten the attention and confidence of army folks to believe in using nanotech for the individual soldier," he says. "Big success will be if we actually put something tangible in a soldier's hands." It won't be easy. But given the institute's head start on materials development, the U.S. Army has at least a fighting chance of getting the uniform it seeks.

JOHN MACNEILL; SOURCE: TIM SWANGER



Test run: In Tim Swager's lab, researchers are testing a tiny sensor similar to the one that might wind up sensing nitric oxide in a soldier's breath.
PHOTOGRAPH BY KATHLEEN DOOHER



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Genetic scrutiny: Leeanda Wilton, a geneticist at Melbourne IVF, uses screening tools to select healthy embryos before implantation.

PHOTOGRAPH BY MICHAEL AMENDOLIA NETWORK/CORBIS/SABA

NEW TECHNOLOGIES OFFER A WINDOW ON THE GENETIC FATE OF THE UNBORN. THE CONSEQUENCES: MORE SUCCESSFUL PREGNANCIES, HEALTHIER BABIES—AND SOME GUT-WRENCHING ETHICAL CHOICES.

BY JON COHEN

FETAL FORTUNES

In 1999, a 36-year-old woman in Australia decided to try in vitro fertilization after seven years of attempting to become pregnant. Doctors stimulated her ovaries with hormone shots, performed minor surgery to harvest eggs, which were fertilized in a petri dish and then transferred into her uterus. In four separate attempts, a total of eight embryos made from this same batch of eggs were transferred into her body. All failed to implant.

The woman opted to try again. Researchers at her fertility clinic, Melbourne IVF, made nine new embryos but this time decided to check the chromosomes in each one. Nearly all embryos with too few or too many copies of some chromosome—rather than the normal complement of 23 pairs—will fail to implant or will miscarry shortly after implantation. (Down's syndrome, by far the most common such abnormality among surviving infants, is caused by three copies of chromosome 21.) To assess the chromosomes, a team of scientists led by geneticist Leeanda Wilton removed one cell from each three-day-old embryo. To each cell they added fragments of DNA—labeled with fluorescent tags—that bound to complementary sequences on the five chromosomes most susceptible to abnormalities. The tags showed that all but two of the removed cells had either an extra or a missing copy of a chromosome. The researchers then transferred the two seemingly normal embryos. Neither took.

The woman went through yet a third cycle. This time, Wilton and her coworkers, taking no chances, turned to a new technique called comparative genomic hybridization to analyze each embryo's entire set of chromosomes. Only one of the five embryos appeared normal—chromosomally speaking. "It wasn't a particularly great-looking embryo," Wilton says. Still, the lone normal embryo was transferred. Nine months later, the woman gave birth to a healthy daughter.

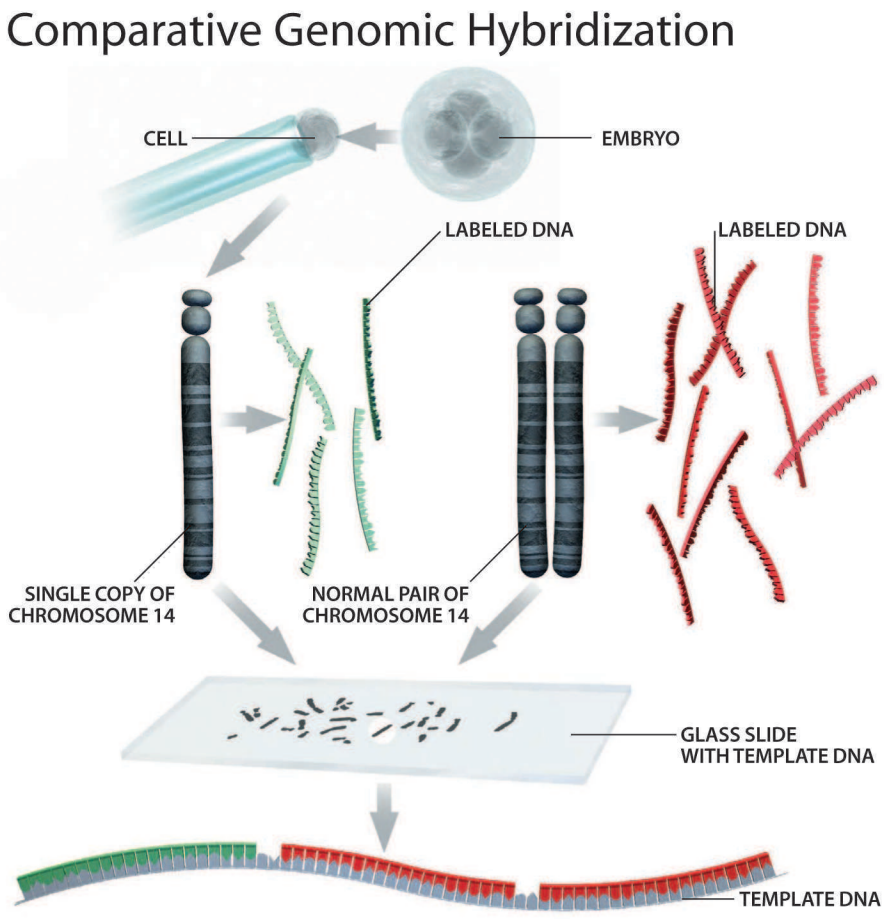
So-called preimplantation genetic diagnosis is now common practice at dozens of in vitro fertilization clinics around the world. The procedure, which was introduced in the early 1990s as a way to determine whether an embryo had inherited the genes that cause fatal diseases such as cystic fibrosis and Huntington's, can now identify more than 50 different genetic diseases. And as the Australian case demonstrates, the technology is playing an ever expanding role in the success of fertility clinics, allowing physicians to detect severe chromosomal abnormalities and carefully choose embryos for implantation.

But this flood of new genetic information on the unborn is reaching far beyond the world of in vitro fertilization clinics. Amniocentesis and chorionic villus sampling, the two techniques that since the 1970s have been mainstays in the diagnosis of chromosomal problems in fetuses, both now incorporate a panoply of tests for inherited genetic diseases. At the same time, researchers are developing safer, noninvasive means of assessing fetal health, two of which have made inroads in clinics around the world: ultrasound screening of body features associated with genetic abnormalities, and blood tests for proteins and hormones that are markers for Down's syndrome and other diseases.

All of these new tests vary in risk or usefulness, and some remain highly controversial. Yet they all serve the same purpose: to provide parents with the information needed to select an embryo or to determine the fate of a fetus on the basis of its genetic makeup. "The changes to come are going to be even more profound as we get into more sophisticated genetic testing," says Rebecca Smith-Bindman, a radiologist at the University of California, San Francisco.

ULTIMATE PREVIEW

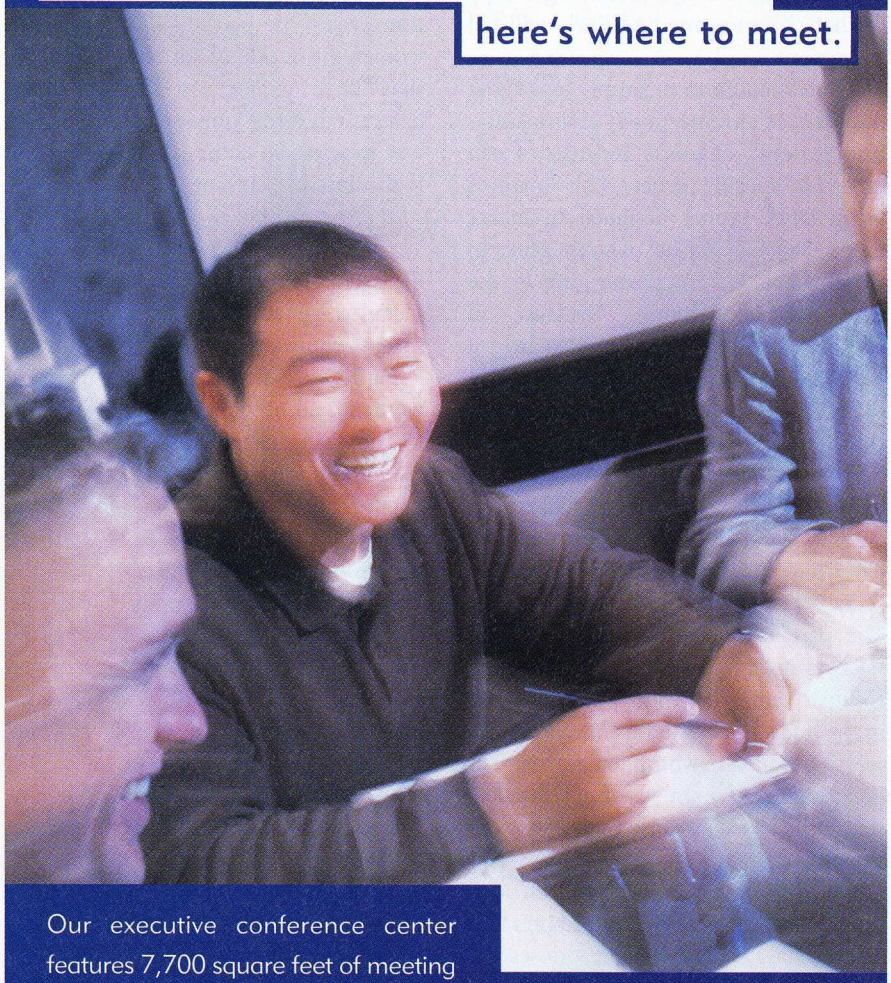
Although studies have proven that chromosomal abnormalities in offspring become more prevalent as a woman ages, researchers have widely varying estimates of how frequently errors occur. Santiago Munné and colleagues at the Institute for



Detecting for chromosomal defects, researchers label DNA from an embryo with a green tag, and DNA from a normal cell with a red tag. Both are added to a slide, where they compete in binding to template DNA. The high ratio of red to green indicates a missing copy of chromosome 14.

JOHN MACNEILL

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AN MIT ENTERPRISE
TECHNOLOGY REVIEW

Reproductive Medicine and Science of Saint Barnabas in Livingston, NJ, have shown that up to 70 percent of embryos produced in their clinic for in vitro fertilization—typically for older women with fertility problems—have chromosomal abnormalities that would likely prevent them from properly implanting. But traditional preimplantation genetic diagnosis techniques have failed to have a dramatic impact on success rates.

Comparative genomic hybridization—the technique that worked for Leeanda Wilton in Melbourne—could change that. A shortcoming of standard preimplantation testing is that it can analyze only a handful of chromosomes from each embryo. Wilton and coworkers have shown that analyzing all of an embryo's chromosomes with comparative genomic hybridization detects 75 percent more errors.

Originally developed to detect abnormal amounts of DNA in cancer cells, comparative genomic hybridization compares the number of chromosomes in an embryonic and a normal cell. Researchers remove a single cell from an embryo, labeling its chromosomes with a green fluorescent tag and attach a red fluorescent tag to the chromosomes taken from the normal cell. Next, researchers add both the green and red chromosomes to a set of chromosomes on a glass slide, where they bind to complementary sequences. Software analyzes the fluorescent signals *(see "Comparative Genomic Hybridization," p. 56)*. If the embryo is healthy, each set of reference chromosomes should have an equal amount of red and green. If there's more red than green in, say, chromosome 14, it indicates that the embryo is missing a copy of that chromosome and likely will fail to implant.

But in addition to simply looking at numbers of chromosomes, preimplantation genetic diagnosis techniques can look for specific genes. This involves using DNA probes designed to marry themselves to parts of a given gene. In 1999 Yury Verlinsky, who directs the Reproductive Genetics Institute in Chicago, used this technique to help a woman undergoing in vitro fertilization select an embryo that did not have the gene for a heritable life-threatening blood disease. An international uproar ensued because the parents also picked an embryo that had the same immune system genes as their daughter, who was five years old at the time and had the disease. The parents hoped that doctors could safely transfer stem cells—which have the ability to differentiate into any type of cell in the body—harvested from the umbilical cord of their newborn to help their ailing daughter. A baby was born in 2000, stem cells were transfused and the older sibling is doing well.

Verlinsky, who has strongly defended the ethics of this intervention, argues that qualms about such genetic diagnoses will subside as the technique continues its inexorable progress from cases of concerned parents who carry known disease genes to those of parents with no known genetic-risk factors but who have difficulty conceiving a baby. "It will probably become routine in all in vitro fertilization cycles," he predicts. It would offer women the option of discarding embryos that have genetic or chromosomal defects. "It's the only scientific proven way to select an embryo. Everything else is absolutely irrelevant."



First checkup: An ultrasound taken at Cedars-Sinai Medical Center in Los Angeles shows a healthy fetus at 12 weeks. Crosses indicate the nuchal region.

COURTESY OF CEDARS-SINAI MEDICAL CENTER

PLAYING THE ODDS

Detailed genetic diagnostic tests may soon become routine for women undergoing in vitro fertilization. But for most women who become pregnant, the tools for detecting genetic defects still offer risks and uncertainties.

It is a warm London morning in June, and Kypros Nicolaides is bouncing from room to room in the Fetal Medicine Centre, a clinic just down the block from the city's majestic Royal Academy of Music. An obstetrician and gynecologist who runs the Harris Birthright Centre for Fetal Medicine at King's College Hospital and, one day a week, this private clinic, Nicolaides has his own intimate relationship with sound: he has developed an international reputation for pushing the bounds of prenatal ultrasound.

In an examination room, Nicolaides greets a 31-year-old woman, 13 weeks pregnant, who has been anxiously awaiting him. As a technician moves an ultrasound transducer over the woman's belly, Nicolaides points to a monitor that shows the grainy image of a fetus. He then has the technician focus in on the folds of skin behind the fetus's neck.

Over the past 10 years, Nicolaides has convinced many of his colleagues that looking for fluid in this region, in a procedure called a nuchal translucency screen, can in the first trimester reveal cases of Down's syndrome as well as other even more severe syndromes that result from extra copies of chromosomes 13 and 18. The ultrasound shows that this woman's fetus has a slightly larger than normal nuchal translucency measurement, but Nicolaides assures her that it's nothing to worry about.

On a separate computer screen, software developed by Nicolaides' foundation graphically shows the risk this fetus



Sound diagnostics: Kypros Nicolaides, pictured at his Fetal Medicine Centre in London, is an advocate of using ultrasound to image anatomical features that can be indicators of genetic abnormalities.

PHOTOGRAPH BY BARRY LEWIS NETWORK/CORBIS/SABA



In the lab: Tufts University's Diana Bianchi is developing an experimental technique to analyze fetal DNA from the mother's blood.

PHOTOGRAPH BY JOHN SOARES

has of a chromosomal abnormality. By the woman's age alone, the risk factor is one in 650. The nuchal translucency slightly increased the risk to one in 600. But earlier that morning, Nicolaides' team drew blood from the woman and analyzed it for a protein associated with these chromosome problems and for levels of a pregnancy hormone that serves as a marker for abnormalities. With the blood tests factored in, her risk plummets to 1 in 1,000, making her look like a woman in her early 20s. But then the woman tells Nicolaides that she had previously conceived a baby with Down's syndrome, a pregnancy that she had terminated. Plugging that into the software, Nicolaides calculates her risk to be one in 180.

The woman and her husband decide then and there that they want to have a chorionic villus sampling performed. Nicolaides explains that this procedure, in his hands, carries a risk of one in 200 or so, maybe higher, of causing a miscarriage. They weigh the options but are resolute. Nicolaides, under guidance of the ultrasound, inserts a catheter into her abdomen and removes fetal cells from the villus—the area that links the part of the placenta known as the chorion to the mother's uterus. The cells are then sent to the lab for chromosome analysis.

Both chorionic villus sampling and its diagnostic cousin amniocentesis can detect Down's syndrome, spina bifida and many other disorders with 99 percent accuracy. Adding to their value, they have a low "false positive" rate: when they report that a problem exists, they are hardly ever mistaken. But because, on average, both of these invasive tests cause miscarriages up to 1.5 percent of the time, they are also extremely dangerous.

Indeed, in the opinion of Nicolaides and others, many more women than ought to undergo amniocentesis and chorionic villus sampling, given the risks of the procedures and the odds of detecting a fetal abnormality. This concern has driven the development of Nicolaides nuchal translucency test and several noninvasive blood screens. Vivienne Souter, an obstetrician and gynecologist at the University of Washington, sees great value in these new technologies. "If we can get better screening with higher sensitivity and lower false positivity," says Souter, "we can potentially save babies' lives."

In the United States, a multicenter trial is now recruiting 40,000 pregnant women as subjects and will perform the most rigorous analysis yet of nuchal screens and various blood markers used in both the first and second trimester. Fergal Malone, a perinatologist at Columbia University and the coprincipal investigator of the study, says he expects to have results by the winter of 2003. "If we choose the right combination of screening tests, we could have detection rates as high as 90 to 95 percent with a one percent false-positive rate," says Malone. "That would be a huge advantage."

Many clinicians contend that, as ever increasing computing power improves the resolution of ultrasound, screening of the nuchal region and other anatomical features will have an increasing ability to reveal problems. "Fifteen years ago, it was a very blurry image," says Beryl Benacerraf, a radiologist at Diagnostic Ultrasound Associates in Boston. She published a report in 1985 about the promise of nuchal screening. "As it's gotten better and better, the images look more like Kodak pictures."

FISHING FOR DNA

One of the most promising prenatal diagnostic tests in the works might one day eliminate altogether the need for amniocentesis or chorionic villus sampling. Its strategy: testing the mother's blood for fetal DNA. For years, Diana Bianchi, a neonatologist and medical geneticist at the Tufts-New England Medical Center in Boston, and others had hoped that fetal cells found in maternal blood might provide a noninvasive means for assessing a baby's genetic makeup. But, Bianchi explains, the cells proved too few in number and thus too difficult to find. In 1997 a team led by Dennis Lo of the Chinese University of Hong Kong first reported the discovery of fetal DNA floating freely in maternal serum and plasma. Since then, preliminary evidence from Bianchi's group and other researchers has shown that this fetal DNA can be assessed for chromosomal or gene defects.

Bianchi cautions that the approach has several critical limitations right now—not the least of which is that researchers have determined how to fish out only male fetal DNA, which is easier to see because of its distinctive Y chromosome. But she predicts that given the speed with which this technology has moved forward, in five years it may have developed far enough to actually turn up in the clinic. "Fetal DNA opens a whole area of new research that is going to be huge," predicts Bianchi.

As ever more information pours out about the relationship between genes and diseases, and as screening tools become more sophisticated, prospective parents will inevitably face harder decisions about the types of babies they want to bring into the world. New tools such as DNA microarrays could soon enter the arena of preimplantation and prenatal genetic diagnosis, allowing physicians to screen DNA for a host of genetic diseases simultaneously.

Prenatal screens and diagnostics cannot eliminate all of the uncertainties about the health of a newborn. They can dramatically reduce them, though, and that is the aim of the technologies. But the same diagnostics also raise vexing ethical questions. As the technology continues to advance, parents will gain the ability to determine whether their offspring have genes that "predispose" them to diseases such as Alzheimer's or breast cancer. In the end, these future tests could themselves introduce ethical ambiguities that no amount of science and technology can overcome. TR

Genetic Diagnostic Tools

TECHNIQUE	APPLICATIONS	LIMITATIONS
Comparative genomic hybridization	Chromosomal or genetic diagnosis before implantation	Limited to in vitro fertilization
Amniocentesis	Genetic diagnosis in the second trimester	Invasive, high risk of miscarriage
Chorionic villus sampling	Genetic diagnosis in the first trimester	High risk of miscarriage
Free-cell fetal DNA	Noninvasive genetic diagnosis	Under development

HOW THE WORLD'S LARGEST MANUFACTURER OF CARS AND TRUCKS IS USING TECHNOLOGY TO TURN ITSELF INTO A "SMALL" AND PROFITABLE COMPANY.

GM'S

The Advanced Design Studio on General Motors' massive technology campus in Warren, MI, feels like a Silicon Valley software startup from the halcyon days. Three six-meter "power walls" snake across one section of the room, displaying far-larger-than-life, 3-D projections of vehicles in progress, for everyone to examine and dissect.

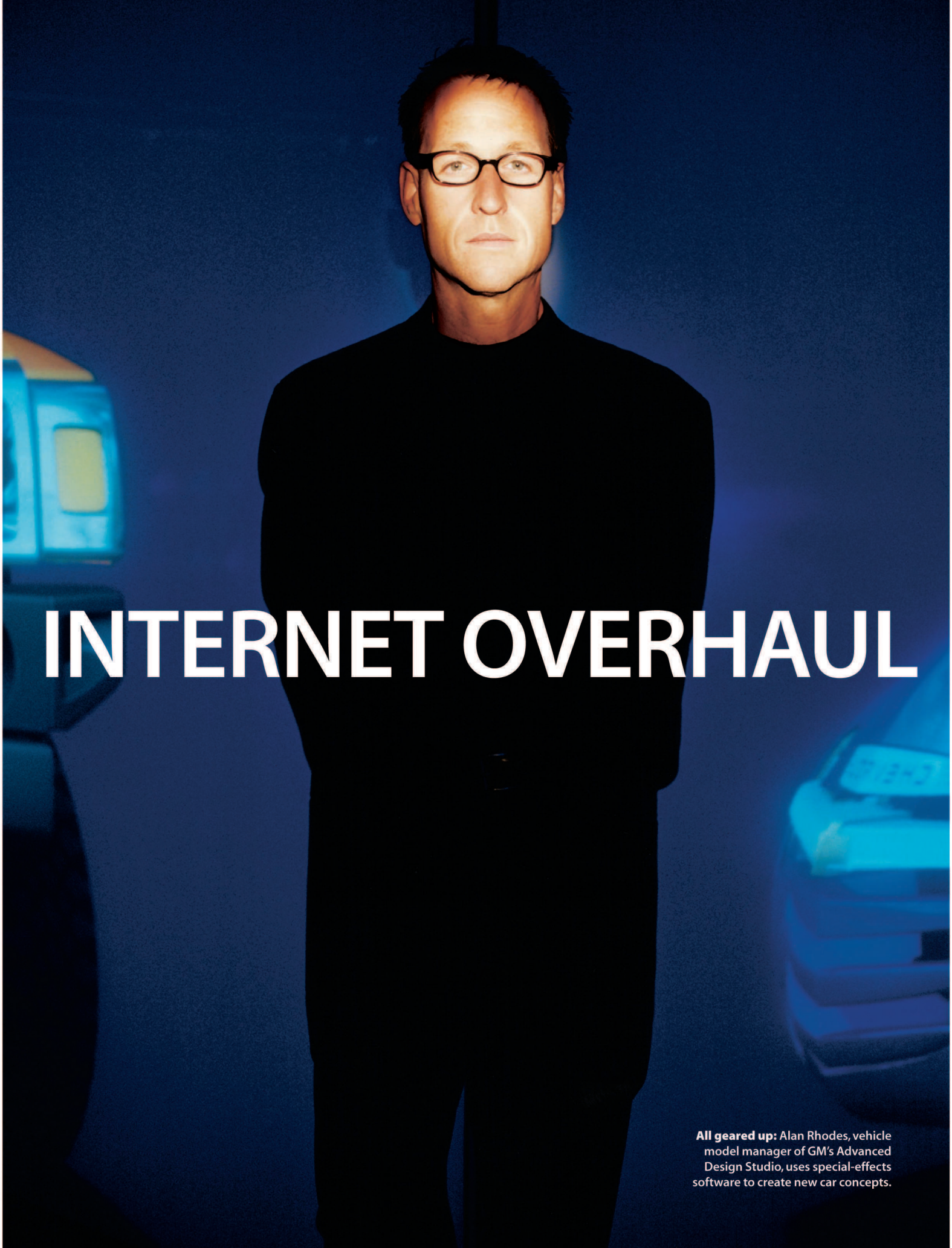
In a dimly lit corner of the room, engineers, designers, digital sculptors and software programmers sit side by side, their faces illuminated only by the light from their computer screens. Alan Rhodes, vehicle model manager of the studio, addresses the Smart Board, a 127-centimeter flat-panel computer display synchronized with the power wall. With the tip of his index finger, he maneuvers 3-D sketches of upcoming GM vehicles around the screen, alternating between views of the Chevy SSR (Super Sport Roadster)—a retro-styled convertible pickup truck unlike anything GM has ever built—the Pontiac Solstice concept car and a new Hummer called the H2.

Designing and displaying vehicle models in software is a relatively new capability for GM, the world's largest manufacturer of cars and trucks. Just a few years ago, all sketches were created by hand and stapled to a display board for review. Clay or hard Styrofoam models had to be sculpted for each new design.

Now, with all 14 GM engineering centers digitally synchronized via a corporate intranet and all using standard computer-aided-design software and 3-D simulation tools, designers in Holden, Australia, Russelsheim, Germany, and North Hollywood, CA, can collaborate around the clock. Most important, the new technology allows GM's senior management to review fully realized designs in a far timelier manner than ever before.

BY GLENN RIFKIN PHOTOGRAPHS BY ROBERT DELAHANTY

INTERNET OVERHAUL



All geared up: Alan Rhodes, vehicle model manager of GM's Advanced Design Studio, uses special-effects software to create new car concepts.



Mission control: Designers and engineers collaborate at the Advanced Design Studio on GM's technology campus in Warren, MI.

"We're using the technology they used to make *Toy Story*," Rhodes says, referring to the hit film digitally animated by Pixar Studios. "With this, we can get feedback right away. We integrate real people into the animation so that we can check spatial relationships within the cockpit of the vehicle."

Indeed, Rhodes points out that several recent hires have come from the motion picture industry. "We used to hire strictly fine-arts majors and automotive-design grads," he says. "Now we're recruiting computer game designers and people from the film industry." To get his team's creative juices flowing, Rhodes sometimes runs films such as *The Matrix* on the power wall during lunch hours.

None of the cars whose high-tech images flashed on the power wall resemble your father's Oldsmobile—or Chevy, Buick or Pontiac. But this is not your father's GM. The Advanced Design Studio is part of one of the largest technological overhauls in corporate history. All told, the $180 billion automotive behemoth has invested more than $1.7 billion in Internet applications while eliminating 3,500 older, or legacy, information systems. By renovating its bloated and outdated technology infrastructure, GM has become nearly unrecognizable as its former self and, without much fanfare, changed nearly a century's worth of automaker tradition in Detroit—and, possibly, the world.

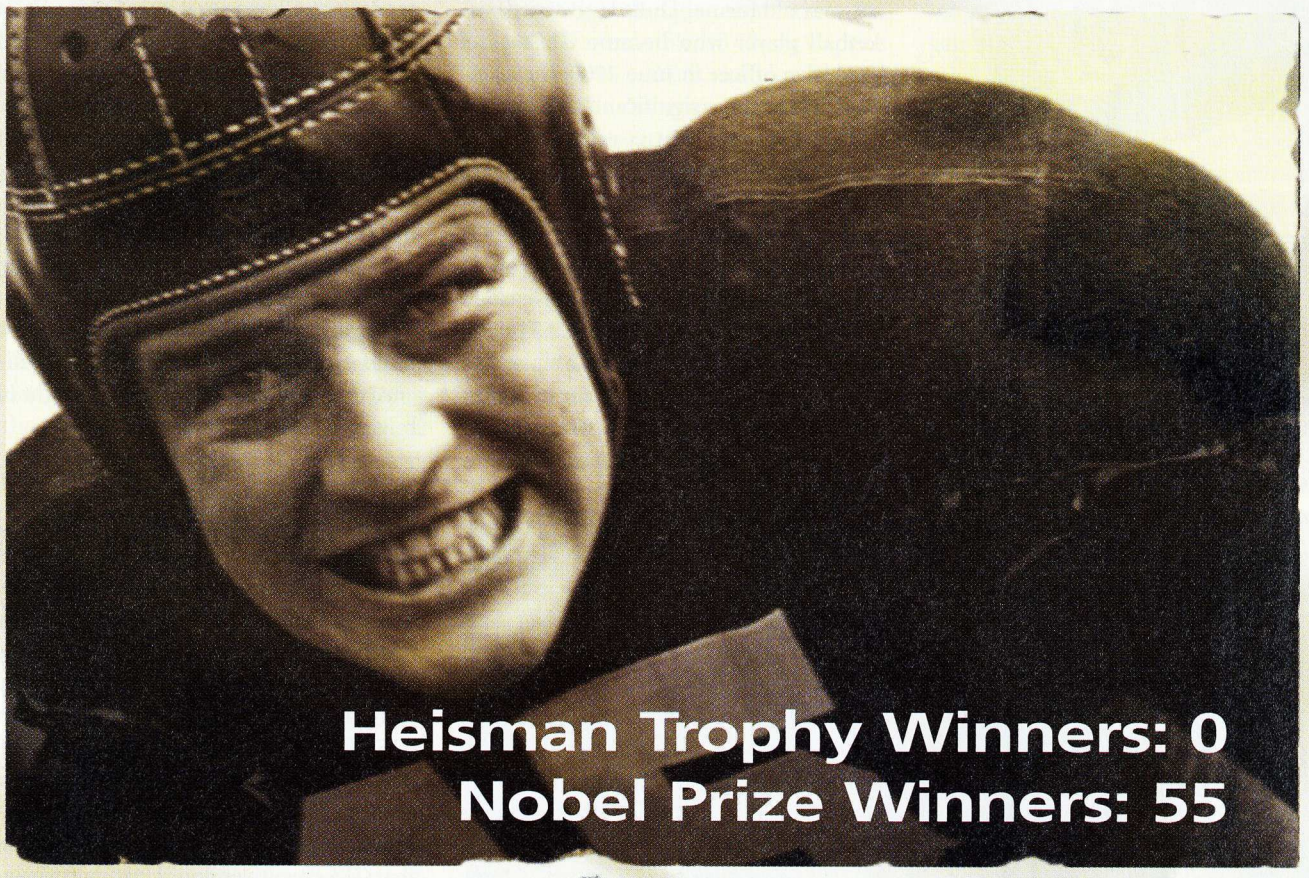
Vehicles that once took four years to design and build are now being created in 18 to 21 months, as GM pushes for greater efficiencies and quality. The company is now introducing a new vehicle every 23 days. That translates to twice as many annual product launches as at any other period in its history. The cumbersome and expensive physical processes of model building and crash testing have been streamlined by the introduction of digital simulation technology. The technological changes even seem to have unlocked designers' creativity, once the victim of GM's overwhelming bureaucracy, resulting in a generation of cars and trucks with radical designs.

Such rivals as Ford, Daimler/Chrysler and even Toyota, which was long renowned for its homegrown and efficient product design process, have made similar commitments to technology. But GM is clearly leading the way, according to Thilo Koslowski, lead automotive analyst for the research firm Gartner. "Even compared to the Japanese," he says, "GM has been the most aggressive company in using technology to change business processes."

REMAKING A GIANT

It would be difficult to find a corporate giant more unlikely to achieve information age glory than GM. Tagged for much of the past three decades with adjectives like staid, slow-moving, bureaucratic and moribund, GM had been slowly suffocating from its own inertia. Plagued by bloated cost structures, labor troubles, forgettable products and intensifying global competition, GM had watched helplessly as its market share slid from nearly 60 percent in the 1960s to less than 30 percent by the 1990s. As the millennium approached, GM seemed stuck in the slow lane as its big-three rivals Daimler/Chrysler and Ford Motor prepared to roar past.

COURTESY OF GENERAL MOTORS



Anthony Anderson, MIT Engineers, 1953. From MIT Museum and H. Armstrong Roberts.

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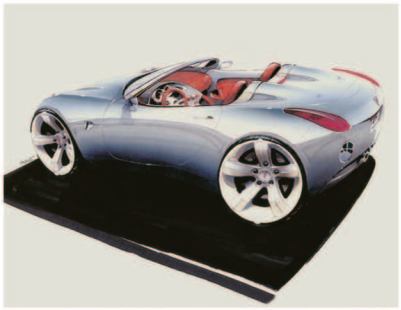
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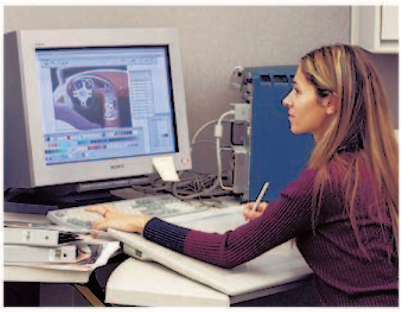
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The idea assembly line: Vehicles that once took four years to design and build are now being created from concept (top) to model (bottom) in 18 to 21 months using Internet-based systems.

But under G. Richard Wagoner Jr., the 49-year old former Duke University basketball player who became GM's chief executive officer in June 2000, the company has begun a significant, technology-driven overhaul that is already paying dividends. As rival Ford fell from grace with a $5.5 billion loss in 2001, GM wowed Wall Street with surging earnings and several quarters of sustained growth. Excluding special charges, GM earned $1.5 billion in 2001 and nearly $2.3 billion in the first six months of 2002 alone.

Technology lies at the heart of almost every aspect of Wagoner's strategy. GM now has initiatives to introduce new information technology throughout its organization, touching all 362,000 employees. The company's disparate information systems, which included everything from 128-megabyte personal computers to 2.5-gigabyte workstations, have been upgraded to a common desktop environment that facilitates Internet access. Its acclaimed GM Buy Power Web site operates in 40 countries, linking customers and dealers efficiently; since its launch in Brazil in late 2000, more than 90,000 GM Celtas have been sold online directly to customers. GM's OnStar telemetric wireless information service, which is now an option on almost every new car, has more than two million active customers. Streamlining GM's order-to-delivery processes has cut delivery time on part orders from 90 days two years ago to 35 days now. Major capacity increases in telecommunications technology are allowing cross-functional sharing and collaboration, with the promise of shortening the product development cycle. These and other efficiencies are saving the company $1.5 billion annually, with 9,000 GM suppliers now linked in real time to the company via GM Supply Power.

But GM executives such as chief information officer Ralph Szygenda believe technology is having its most significant impact in product development. GM, which sold more than 8.5 million vehicles around the world last year, must have a steady stream of appealing new cars and trucks to fuel its future growth. The company's design and product development teams are responding with what promises to be a wave of new vehicles that are entirely without precedent. For instance, in just a few months, the team produced—from sketch to running model—the Pontiac Solstice, a two-seat roadster so alluring that it was named best in show at the 2002 North American International Car Show by *AutoWeek*.

And that is just a hint of what may be in store. Under legendary designer Robert Lutz, recruited by Wagoner in September 2001 to be vice chairman of product development and chairman of its North American operations, GM is intent on shedding its lackluster image as the purveyor of uninspiring vehicles, and its starting to build market share with a wide new audience that once snickered at the thought of buying a GM car.

DESIGN AND CONQUER

While GM's new cylindrical, steel and glass Renaissance Center tower in downtown Detroit may serve as headquarters for this revival, much of the company's new ideas take shape at the technology campus in Warren. Down the hall from the Advanced Design Studio is GM's Virtual Reality Lab, another dimly lit theater equipped with a wraparound, floor-to-ceiling display wall and special 3-D glasses that GM executives don at design reviews. This is several generations removed from the quirky 1950s version of 3-D projection. Here, a visitor receives a virtual look at the new Chevy SSR from various distances and angles. The digital images are so realistic that sunlight and trees reflect off of the SSR's exterior. Visitors feel as if they can reach out and touch the front grill of the new pickup. Properly positioned, one can occupy the virtual space of the driver's seat and get a sense of the interior or use a sophisticated joystick to tool the prospective vehicle through simulations of downtown Las Vegas or the Bonneville Salt Flats in Utah.

The Virtual Reality Lab, built in 1999 and now linked digitally to GM studios overseas, allows Lutz and his charges to collaborate on product reviews with colleagues across the world. These virtual reviews helped GM designers find an existing platform—the GMC Envoy sport-utility vehicle—upon which to base the SSR pickup, thus saving months and millions of dollars in building clay models. According to Szygenda, the SSR moved from sketch to production in less than 18 months. The entire project was done virtually, up until the construction of a show car.

COURTESY OF GENERAL MOTORS

With its shorter production cycle, GM is much more responsive to changes in consumer tastes. Five years ago, it lagged well behind industry averages in product development. A car slated for the market in 2000 had to be initiated in 1996 or earlier, forcing design committees to gaze into crystal balls to determine what their customers would want in five years. More often than not, they guessed wrong.

The combination of GM's daunting bureaucracy and clunky manual product-development processes also spawned dated, unappealing vehicle design. Executives would often see just one design option for a prospective car or truck. If they recommended a change, it could take months to build a new physical model and get sign-off from manufacturing that the updated version was buildable. Most original designs were redone 50 times before they reached the marketplace, adding years to the process and rendering the initial concepts unrecognizable.

And if creativity is the end, the new technology may be the means. "The idea is to give flexibility to the designer on the front end and build technology that organizes the thought processes that permit creativity," Szygenda says. Not only can designers display dozens of options to senior management, but they can also respond to data gleaned directly from dealers and customers via the Internet. By monitoring buying preferences on GM Buy Power, for example, engineers develop a far better sense of what customers actually want. The company has even experimented with the online design of a vehicle aimed at a younger audience into extreme sports. Iterations of the design were posted online, and prospective customers proposed modifications. While the car was never actually manufactured, designers were able to tap into the minds of potential drivers. "This is a lot better than trying to figure out 48 months in advance what you think customers will want," says Robert M. Ottolini, GM's executive director of engineering process and math strategy.

Actually building and testing those designs before they appear in showrooms is another reason for GM's considerable investment in computer-aided engineering and simulation. The digitization projects are intended to overturn the ponderous "build, test, break" model that it had employed for decades. The goal is eventually to replace all vehicle dynamics and crash testing with digital simulation. Ten years ago, for example, 80 Chevy Caprice test cars had to be built and plowed head on into walls in order to ensure their crash worthiness and to meet other federal regulations. The process was time consuming and—at a cost of between $500,000 and $1 million per test vehicle—expensive. Today, with digital simulation replacing physical testing, the number of test vehicles is down to 10 or fewer, saving at least $35 million per product, despite a steady increase in the number of regulated tests required by the federal government.

"We wanted our engineers to spend more time analyzing vehicle dynamics, crash tests, handling, noise vibration and things like that rather than building models," says Kirk Gutmann, GM's global product development information officer. In order to support all this simulation, the company increased its supercomputing capability, provided by Hewlett-Packard and IBM, by 1,200 percent.

The result is unprecedented excitement and enthusiasm within the product development group. "When engineers are looking at 12-month design cycles, it's a lot more exciting," Ottolini says. "From the time you start working on a design to the time your neighbor can buy the vehicle is not that long. People like that."

THE ROAD MORE WIRED

All this is aimed at making GM a smaller, quicker, more agile organization. The payoff has been double-digit productivity gains in each of the past five years.

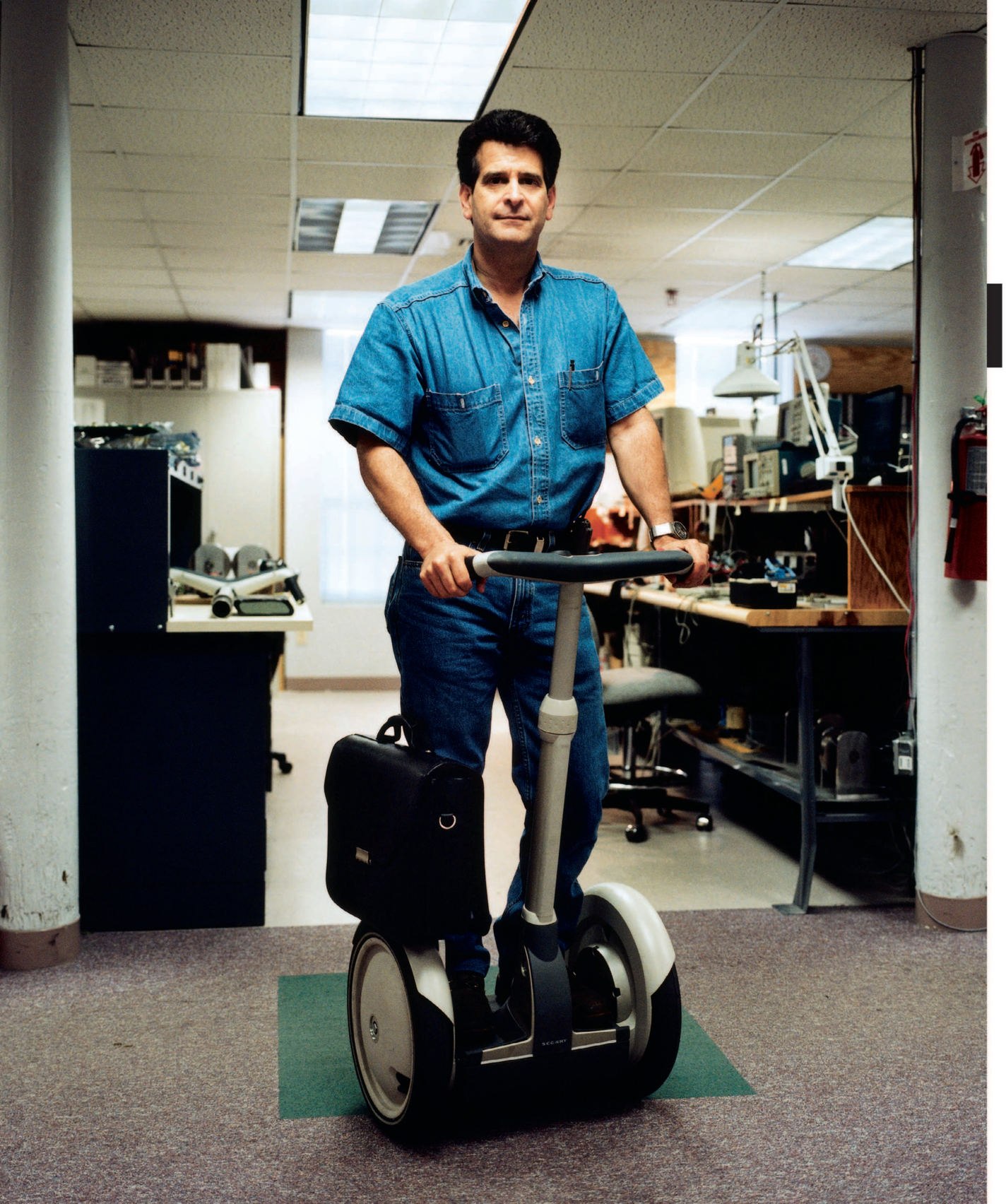
"The real reason GM is so resurgent is purely a story about costs, operational efficiency and productivity," says Baba Shetty, an analyst in the automotive practice at Forrester Research in Cambridge, MA. "How technology can help deliver on the core processes critical to the business—that's where the real story is. Because even incremental improvements will pay off dramatically in the marketplace."

The most notable thing at GM may be its reluctance to blow its own horn. After a tough decade in the 1990s, GM is well aware that the automotive industry is subject more than most to the swift business cycles of the economy. The company still has the challenge of developing distinct brands and brand values in the marketplace so that it is not simply competing on price. Though its technology initiatives have dramatically affected the bottom line already—by increasing productivity and earning good will among customers, dealers, suppliers and employees—everyone agrees there are more ways to use information technology to improve business.

"This will be more of a journey for the next five years," Gutmann says. "There will be fewer big changes but more year-over-year improvements. We're moving closer to real knowledge management, to sharing knowledge across the enterprise. Our goal is to make GM feel like a small company." TR



Digital mock-up: Workstations have replaced clay models in GM's product development offices.



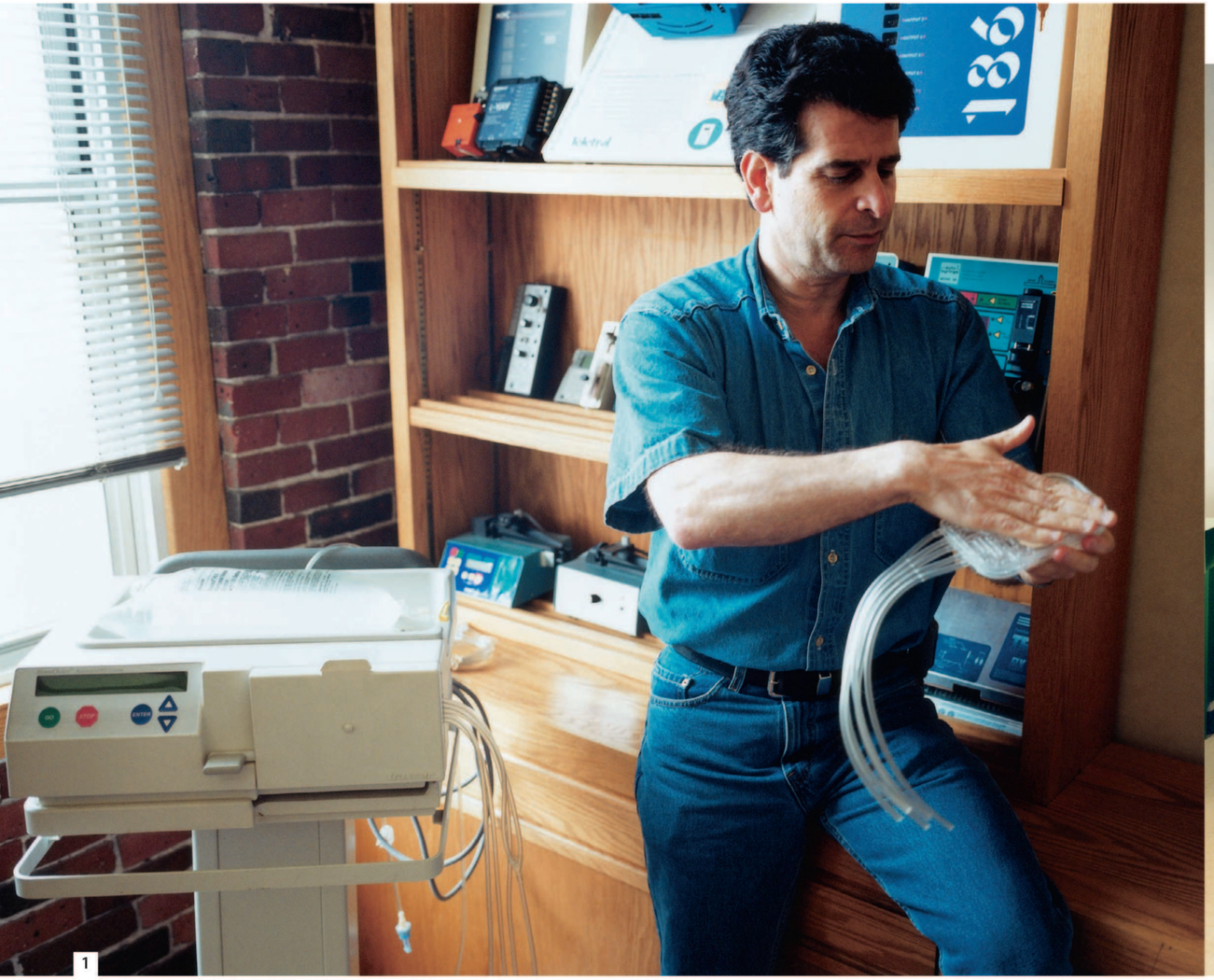
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The Inventor's Play-ground

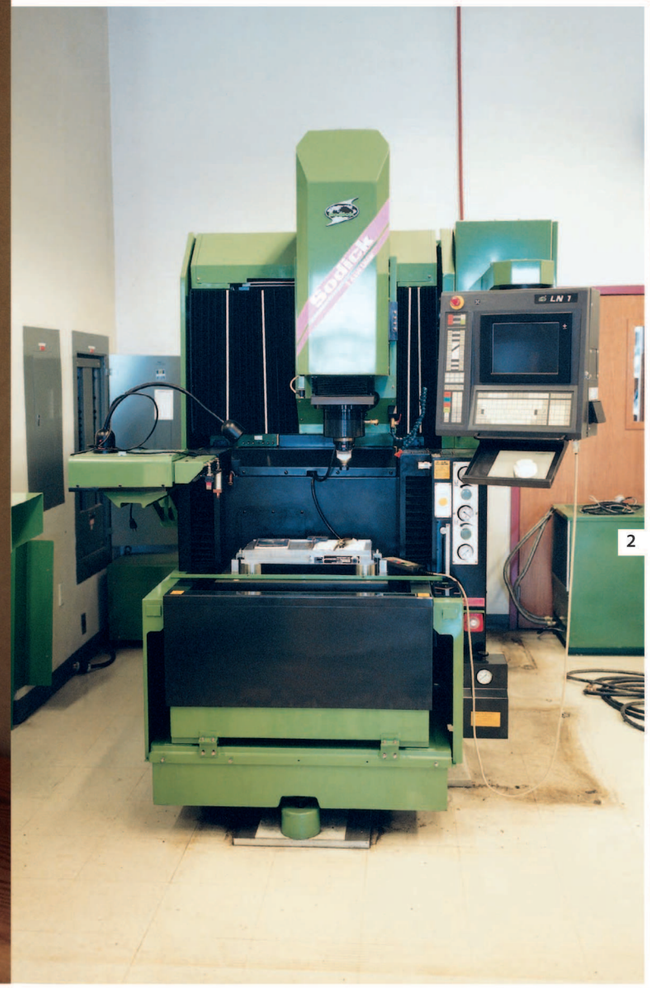
Dean Kamen says that, for him, work is a vacation. Take a tour of the Segway inventor's massive gadget-packed lab and it's easy to see why.

You may know him simply as the inventor of the soon-to-be-mass-marketed Segway transporter (a.k.a. "Ginger," a.k.a. "IT"), but Dean Kamen has a history of invention stretching back to his days as a teenager devising mechanical gadgets in his parents' basement. In 1982 Kamen purchased an abandoned textile mill by the banks of New Hampshire's Merrimack River, and he has invested more than $10 million to transform the red brick buildings into the ultimate inventor's playground. His company, Deka Research and Development, now holds more than 200 patents, many of them on innovative health-care devices, such as a portable insulin pump, a compact dialysis machine and a stair-climbing wheelchair called the iBOT. On a recent afternoon, Kamen led *Technology Review* contributing writer Evan I. Schwartz on a whirlwind tour of the 13,500-square-meter facility, showing off everything from Deka's cavernous machine shop to the nearby Segway spinoff's design and test center, where engineers are fashioning future improvements for the self-balancing, battery-powered transporter. This is where Kamen and 300 employees engage in what they describe as a mysterious and messy process, one in which failure is far more common than success, and no one knows what the final product will look like.

BY EVAN I. SCHWARTZ | Photographs by Beth Perkins



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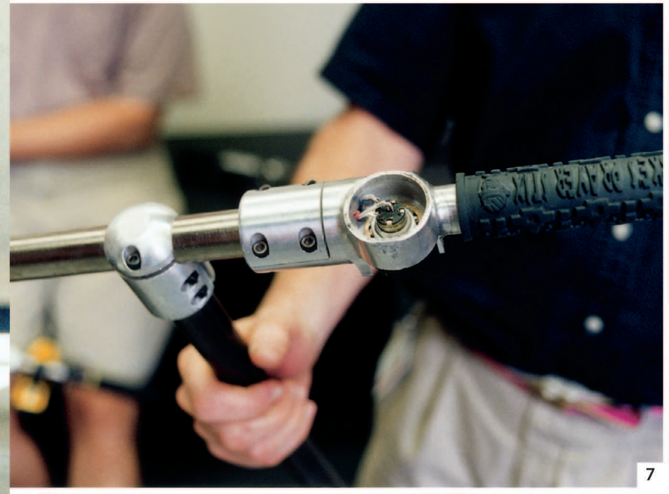
1 FINDING NEW QUESTIONS Perched in front of a gallery of past inventions in Deka's boardroom, Kamen attacks the conventional view of invention. "I can't ever recall sitting down and saying, 'Now it's time to invent something,'" he says. "People think invention is conceiving the finished product, but it's way messier than that." In 1988, for instance, Baxter International proposed that Kamen fix a valve glitch in its dialysis machines, large, expensive devices that required patients with kidney failure to visit treatment centers two or more times each week. Kamen rejected the very premise of the proposal. "What really makes it an invention," he says, "is that someone decides not to change the *solution* to a known problem, but to change the *question*." Kamen's questions became, "What if you can find the technology that not only fixes the valves but also makes the whole thing as simple as plugging a cassette into a VCR? Why do patients have to continue to go to these centers? Can we make a machine that can go in the home, give the patients back their dignity, reduce the cost, reduce the trauma?" The result was the first self-service dialysis machine, now used by thousands of people worldwide.

2 MECHANICAL DOODLING Kamen hops on his Segway and takes off, leading the way down the hall to a machine shop the size of a small city block, where men with goggles and earplugs are extracting tiny parts from colossal, clanging contraptions. This is where Kamen begins to answer some of his reformulated questions, testing new approaches as rapidly and as precisely as possible. "Some people conceive ideas and doodle on the back of a napkin," he says. "We doodle in three dimensions—in stainless steel or titanium or whatever it takes." Kamen pauses in front of a big green machine that uses heat generated by electrical sparks to etch intricate parts. Like many of the devices in the shop, this machine was originally built for manufacturing, not research, but using such machines early in the invention process, Kamen says, ensures that the eventual product will actually be manufacturable. "It doesn't make sense," he says, "to invent things that ultimately are made of unobtanium or expensium."

3-4 BRAINSTORMING PARTS Sometimes, however, building a Deka invention will require a part that's not *yet* obtainable. Kamen motors over to the shop's injection molding machine, where machinist Steve Levesque is working on Kamen's version of the Sterling engine—a 19th-century idea for a single- or double-piston device in which simple heat differentials turn a crankshaft. "This would be part of a ball bearing assembly to hold one of the rotating components," Kamen says, taking a pair of small black plastic parts from Levesque. "Nobody here planned to invent new ball bearings, but in order to make this engine practical we have to develop a bearing technology that doesn't exist," he adds, as Levesque readies the machine to mold another bearing piece.

5 REAL-WORLD PROTOTYPES While most modern laboratories rely on computer-aided-design software for envisioning new products on screens, Kamen prefers physical objects you can hold in your hands and test directly. "There is nothing like real parts," Kamen says, hefting a solid metal fixture—freshly produced on the shop's lathe—that is designed for holding components together inside the Sterling engine.


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6 UNEXPECTED TURNS Kamen scoots out of the shop, into an elevator and up to the third-floor iBOT wing of the lab, where another team is working on a different phase of the invention process. More than 10 years of tinkering produced a wheelchair that can climb stairs and lift the rider into a balanced standing position. Now Deka is working with a subsidiary of Johnson and Johnson to gain U.S. Food and Drug Administration approval for the iBOT, a process that generally takes a little over a year from this point. But another product that grew out of the iBOT research is already hitting the streets: the Segway. "In terms of the balancing technology, the iBOT and the Segway are similar," he says. Each device has multiple gyroscopes that sense changes in direction and adjust accordingly, and each builds on a basic understanding of how people learn to move. "When you're a baby, if you stick your butt out or if you stick your head out, you fall on it," Kamen explains. "So you learn to move your center of gravity in front of your feet, and when you start to fall, you catch yourself on the ball of your foot." Lean forward on the Segway or the iBOT in standing mode, and you go into a controlled fall—only it's the machine that catches you. It's unnerving at first, Kamen admits, but eventually "the machine becomes an extension of yourself."

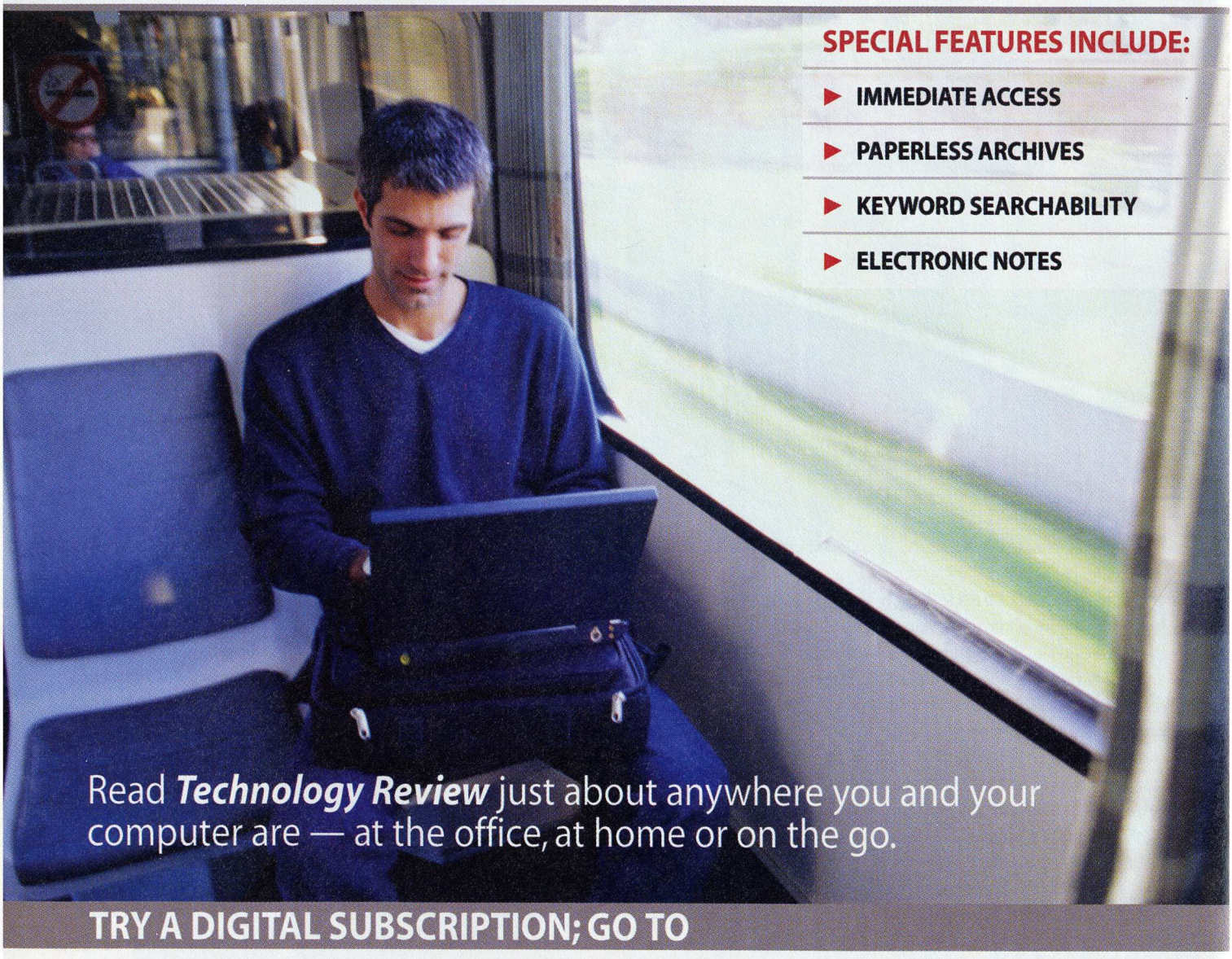
7-10 KISSING FROGS Kamen finally deposits his *TR* visitors with three Segway engineers, who detail perhaps the most painstaking phase of invention: nailing down the final design. Kamen demands that engineers produce, consider and eliminate as many different concepts as possible—it's what he calls "kissing frogs." Vice president of product development Doug Field and engineers John Morrell and David Robinson explain how the process played out in the design of the Segway's handlebar-like user interface. One early prototype of a straight metal bar with a radio-button-like dial for steering *(7)* proved too difficult for riders. "It required a surgeon's touch," says Field. In a subsequent design *(8)*, engineers developed a sleevelike controller for one handle so that a rider could steer with his or her wrist. But the handles, at right angles to the main bar, kept getting caught in riders' belts and shirts. A more rounded M-shaped version *(9)* included more electronics and was crafted out of plastic, which made it easier to manufacture. Yet there were too many buttons and features, Field says, which caused confusion and distraction. In the end, it came down to a design that emphasizes simplicity, using one simple round key to control both settings and security *(10)*. After three years of trial and error, the engineers had finally met their prince, a design elegant enough to present to the laboratory's king. TR

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FRISBEE'S MARKETING WIND

A number of years ago, I stumbled across an old pie tin at a flea market. It was a pretty standard affair with a plain rim and a few small holes punched through the bottom to keep the crust crispy. I'm not much of a baker, but I was fascinated by the familiar name embossed on the bottom: Frisbie's Pies. So I forked over $5, hoping to own a piece of intellectual-property history.

When I got home, I did a bit of research and learned the Frisbie pie tin was, in fact, a predecessor of today's ubiquitous Frisbee flying disc; so I hung the tin on my office wall. And I was reminded of my flea-market purchase recently when I happened to see the newspaper headline "Inventor of Frisbee Dies" over an article about the passing of Arthur "Spud" Melin, 77, in June. It got me thinking about innovation—both where ideas come from and what makes them successful in the marketplace.



Arthur "Spud" Melin no more invented the Frisbee than Bill Gates invented the computer operating system. Yet his marketing genius meant everything in giving the world an iconic plaything.

Melin, whose company Wham-O in 1967 received U.S. patent 3,359,678 for the plastic flying disc, was unquestionably a toy-marketing genius. In addition to the phenomenally successful Frisbee, he also gave kids such iconic playthings as the Hula Hoop, the Superball and the Slip 'n' Slide water toy. Little wonder he was able to sell the company—which he started in his garage as a college student in 1948—for some $12 million when he decided to retire in 1982.

Spud Melin had an enormous impact on my childhood and my whole generation. But he in no way whatsoever invented the Frisbee, despite what the obituary headlines or the U.S. patent office might say. Rather, his story is a reminder that inventing something is rarely as important as what's done with the invention afterward. In high-tech fields, we are often so fixated on new creations that we forget that being first is usually not as important as being best. Indeed, the history of the Frisbee makes a pretty good parable about modern-day invention.

Flying discs have ancient roots, of course; 2,500 years ago, the discus throw was part of the Olympic Games. But the history of the modern-day Frisbee has more to do with Frisbie Pie of Bridgeport, CT. Founded by William Russell Frisbie in 1871, the bakery was a scant 30 kilometers from the student hordes of Yale College in New Haven, CT. Yale students, it seems, were wild about Frisbie's pies. And after eating them, the students would burn off their sugar highs by tossing the metal pie plates around.

Testimonials about Frisbie pie tin throwing date to the 1920s, possibly earlier. The tradition is thought to have peaked in the mid-1950s, when Frisbie Pie was producing as many as 80,000 pies per day. Around this time, a building inspector named Fred Morrison had the idea of making the pie tins particularly well suited for throwing by molding them out of that new wonder material, plastic. In fact, it was Morrison who in 1958 got the first U.S. patent on a "flying disc." He had some success hawking his toy at county fairs (he called it the Pluto Platter) before selling the idea to Melin at Wham-O.

Wham-O didn't have much luck with the Pluto Platter at first. But legend has it that sometime at the end of the 1950s, Wham-O cofounder Richard Knerr made a tour of Ivy League college campuses and learned that students were following Yale's lead and calling pie tin throwing "Frisbie-ing." Knerr misspelled the name as "Frisbee," and the rest, as they say, is history. Wham-O has reportedly sold 100 million of the flying discs—which may even make for a new Olympics competition one of these years, in the form of the popular team sport ultimate Frisbee.

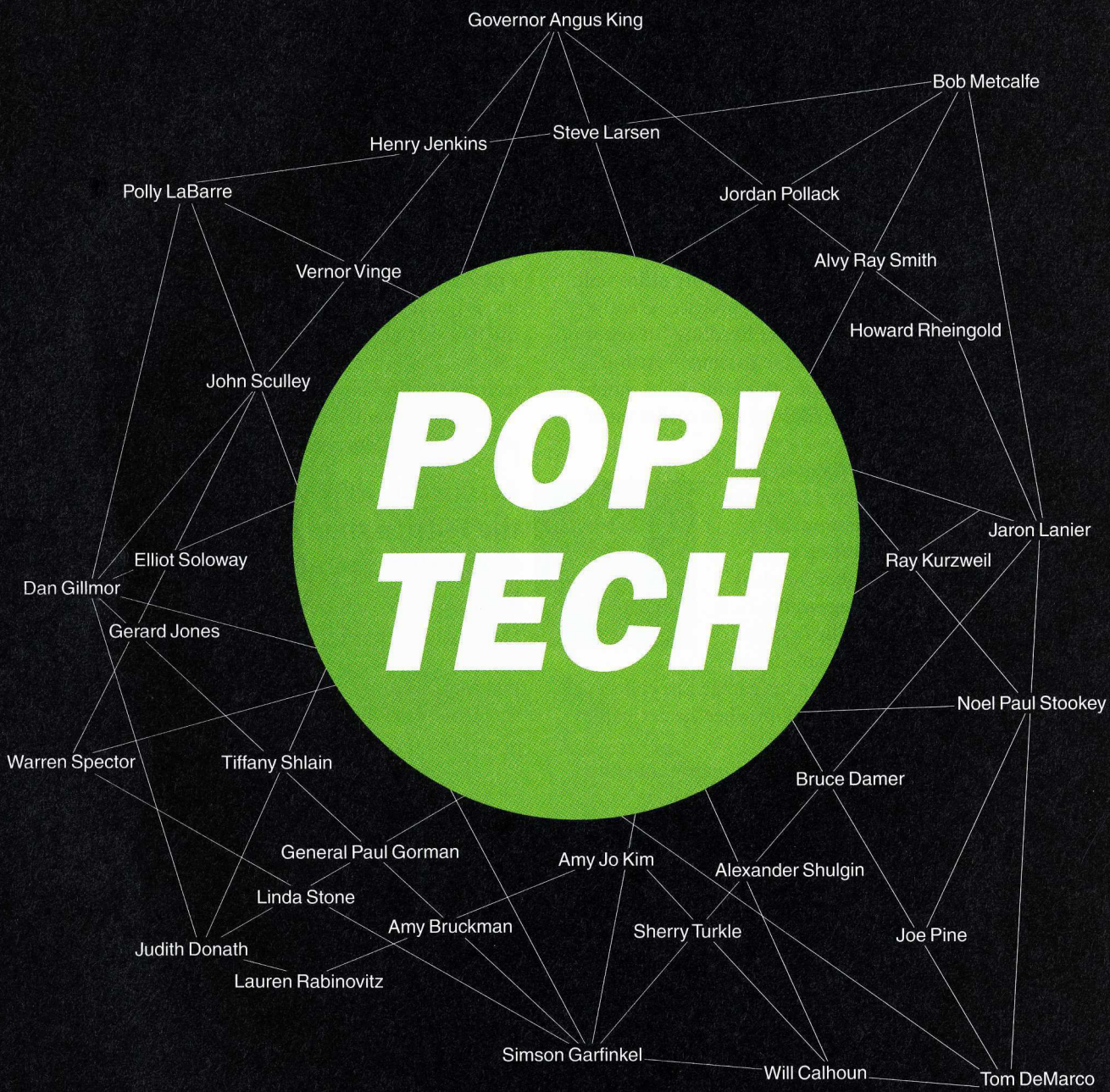
So who invented the Frisbee? Certainly not Melin. He simply bought Morrison's technology. Some might suggest that Morrison deserves the recognition. After all, he did decide to make the discs plastic and shaped them to fly a bit better. But my vote still goes to the now forgotten groups of raucous Yale students and their tin-throwing counterparts on other college campuses. Like so many other new ideas, or new technologies, the Frisbee was not created out of whole cloth by an individual inventor; rather it percolated up in an existing milieu from the materials at hand.

The obituaries were wrong in their shorthand headlines: Melin no more invented the Frisbee than Bill Gates invented the computer operating system or Henry Ford invented the automobile. And yet, it's hard to overstate his contribution. Like Gates and Ford, Melin took a truly innovative concept that was invented by others, saw its enormous potential and then did the legwork to anticipate and stimulate demand for it. It was Melin who had the vision to market the plastic disc in an appealing way. It was Melin who had the good sense to rename it and repackage it until he captured the youthful market he sought.

So here's to Spud Melin and all the others who spin half-baked ideas into useful, enduring products. When we think about innovation, let's not forget this part of the equation. I still keep my Frisbie Pie tin on my office wall. To me, it's a reminder that ideas are all around us; sometimes where they come from may not be as important as who ultimately makes them fly.

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HOW MICROFLUIDICS WORKS

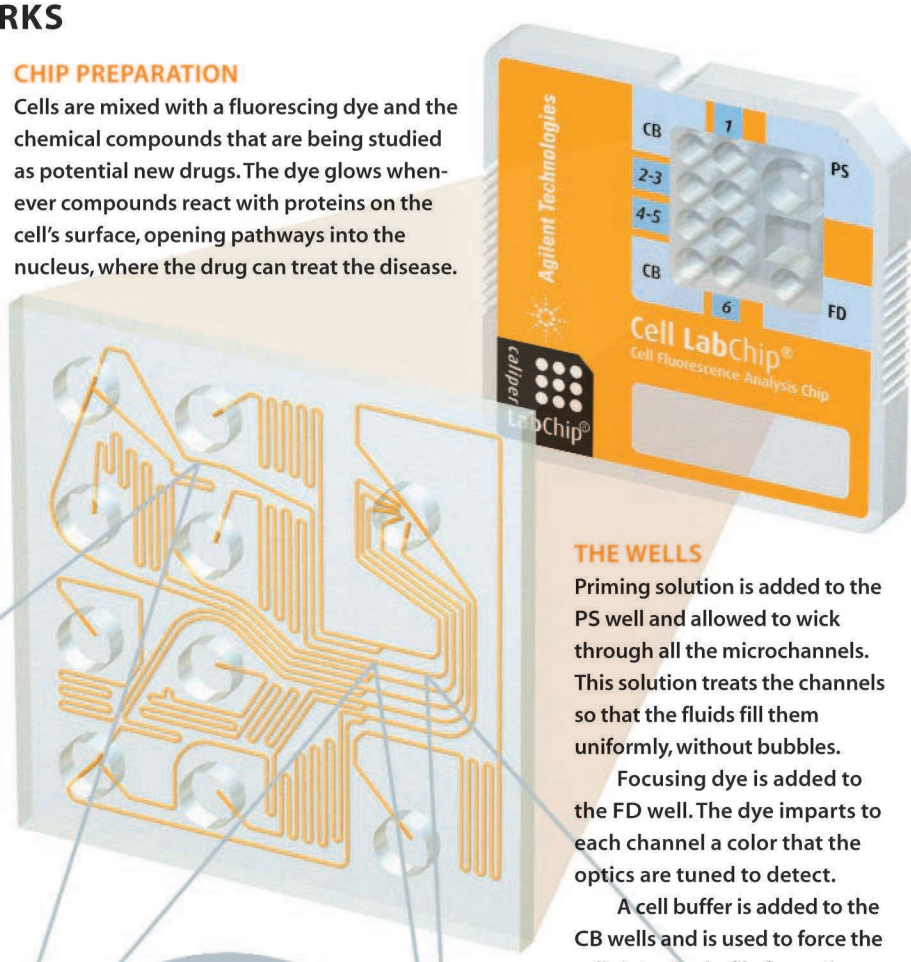
Innovations that have transformed room-size computers into dime-size chips are similarly miniaturizing biotechnology. Laboratory tests that previously required lots of equipment, samples, chemicals and time can now be done on a microscopic scale in cheap, mass-produced devices. This so-called lab-on-a-chip technology can automate thousands of experiments a day with great accuracy, saving on expensive chemicals and precious samples.

The chips rely on microfluidics—the manipulation of tiny amounts of fluids in equally tiny tubes and vessels. Agilent Technologies in Palo Alto, CA, and Caliper Technologies in Mountain View, CA, are collaborating to exploit a property called laminar flow, in ways that promise to speed drug discovery.
—*Tracy Staedter*

For an animated version of this illustration, go to www.technologyreview.com/visualize

CHIP PREPARATION

Cells are mixed with a fluorescing dye and the chemical compounds that are being studied as potential new drugs. The dye glows whenever compounds react with proteins on the cell's surface, opening pathways into the nucleus, where the drug can treat the disease.

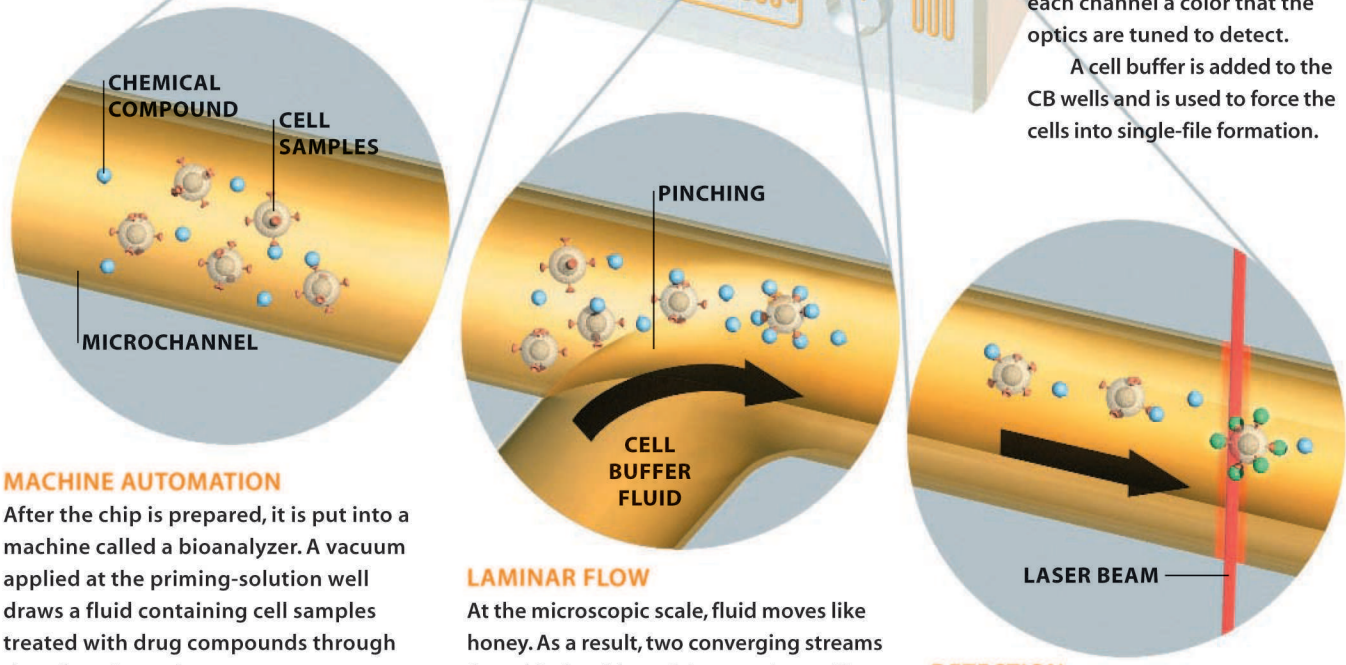


THE WELLS

Priming solution is added to the PS well and allowed to wick through all the microchannels. This solution treats the channels so that the fluids fill them uniformly, without bubbles.

Focusing dye is added to the FD well. The dye imparts to each channel a color that the optics are tuned to detect.

A cell buffer is added to the CB wells and is used to force the cells into single-file formation.



MACHINE AUTOMATION

After the chip is prepared, it is put into a machine called a bioanalyzer. A vacuum applied at the priming-solution well draws a fluid containing cell samples treated with drug compounds through the microchannels.

LAMINAR FLOW

At the microscopic scale, fluid moves like honey. As a result, two converging streams flow side-by-side and do not mix readily—a property known as laminar flow. When the buffer fluid meets the cell samples, it gently pinches them into single-file formation. It's better than forcing them down a narrower channel, where they'd jam up.

DETECTION

With the help of laminar flow, cells pass through a laser beam and are analyzed one by one. The dye fluoresces wherever a drug candidate binds to a cell.

JOHN MACNEILL; SOURCE: CALIPER TECHNOLOGIES

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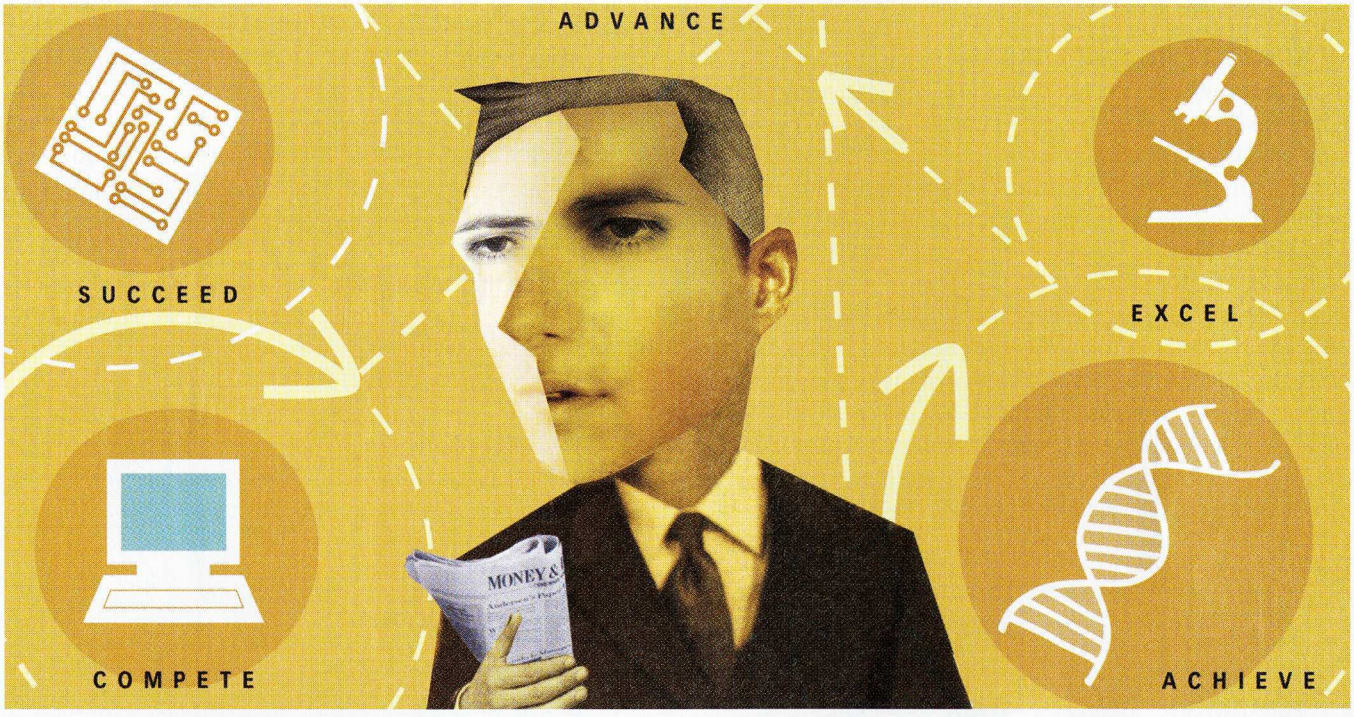
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EXECUTIVE EDUCATION FOR TECHNOLOGY LEADERS

FILLING YOUR KNOWLEDGE GAPS WILL HELP YOU GET AHEAD



MATTHEW BOUCHARD ILLUSTRATION

BY CAROL HILDEBRAND

James Brennan knew he didn't know enough. He wanted to move from operations into general management at Motorola, but there were some knowledge gaps he needed to fill first. As the senior director of operations for Motorola's cable modem division, "I had an engineering and operations background," says Brennan. "But I knew I didn't have the business and leadership skills to balance [the technical ones]."

So Brennan signed up for the six-week, intensive Advanced Management Program at the University of Pennsylvania's Wharton School. The program teaches business courses from finance to strategic planning to leadership. "It really helped me develop my general management skill set," he says.

> "Techies always want to believe that the competitive advantage comes from having a better product. But I can't tell you the number of case studies I've written that show how the best products don't always win."
>
> *– Philip Zerrillo, director, Institute for Managerial Leadership, University of Texas at Austin*

It also paid off in a new position. Brennan, now senior director of strategic planning and merger integration for Motorola's broadband division, credits the course for helping him get ahead. "It gave me a much better frame of reference to manage successfully," he says.

LACK OF SKILLS POSES BARRIER

Like Brennan, thousands of technology-oriented professionals realize each year that they need more knowledge. They could be technical geniuses who want to build and sell their latest invention, or they could be mid-career executives like Brennan who'd like to branch out from a technical base. But they all have one thing in common: They lack the necessary business skills to achieve their goals.

Philip Zerrillo is familiar with stories like these. As director of the

Institute for Managerial Leadership at the University of Texas at Austin, Zerrillo hosts what he calls "Startup Sundays," at which budding entrepreneurs ask about how to launch companies. And invariably, says Zerrillo, technology-oriented folks are long on the tech stuff and short on business acumen. "They may have good instincts and realize that good cash flow is important to starting a business, but they don't recognize how to attract capital to a startup, or price products or negotiate price policies rather than price points."

MONEY FOLLOWS EMBA GRADS

If salary tells the tale, building a well-rounded array of business skills must count as a definite advantage. According to the annual benchmarking survey run by the Executive MBA Council, the mean salary of students entering EMBA programs was $84,800. The mean salary of students leaving those programs: $103,600.

Technology executives have even more reason than those working in other industries to beef up their business and managerial skills, says George Yip, associate dean of the London Business School. Technology itself mutates so fast that the typical technology company must constantly reinvent its business model to keep up. "The classic example is Dell," says Yip. "Their success isn't built on selling innovative technology. They've done it by reinventing their business model every few years".

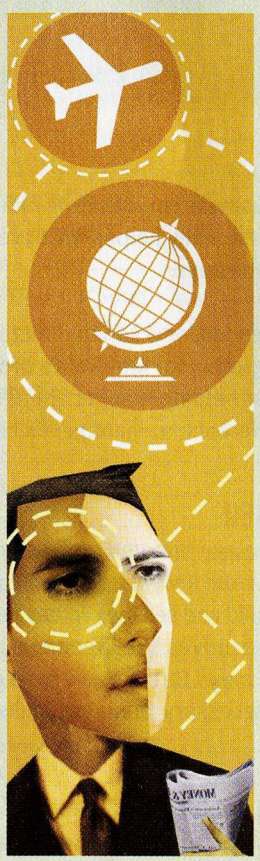
There's another wrinkle to the technology management cloth, according to David Weber, director of the Management of Technology program at MIT in Cambridge, Mass. Growing technology companies tend to acquire a lot of smaller technology firms that have developed bright new products. Weber cites Cisco, which acquired between 75 and 100 startups in the nineties, as being the poster child of this practice. The result is that many executives have to learn skills that "bridge the entrepreneurial divide," Weber says.

BUILDING THE BUSINESS SIDE

There are a wide range of executive education programs available, and each program has its advantages. A quick rundown can help narrow the decision-making process.

- **One-topic certificate programs.** These range in length from one week for a course such as Wharton's "Finance for non-financial executives," to Harvard's 10-week program in leadership.

- **Custom-designed programs.** Custom programs have become increasingly popular. In fact, the top 20 schools earned an estimated 43% of revenues through custom work, with pro-



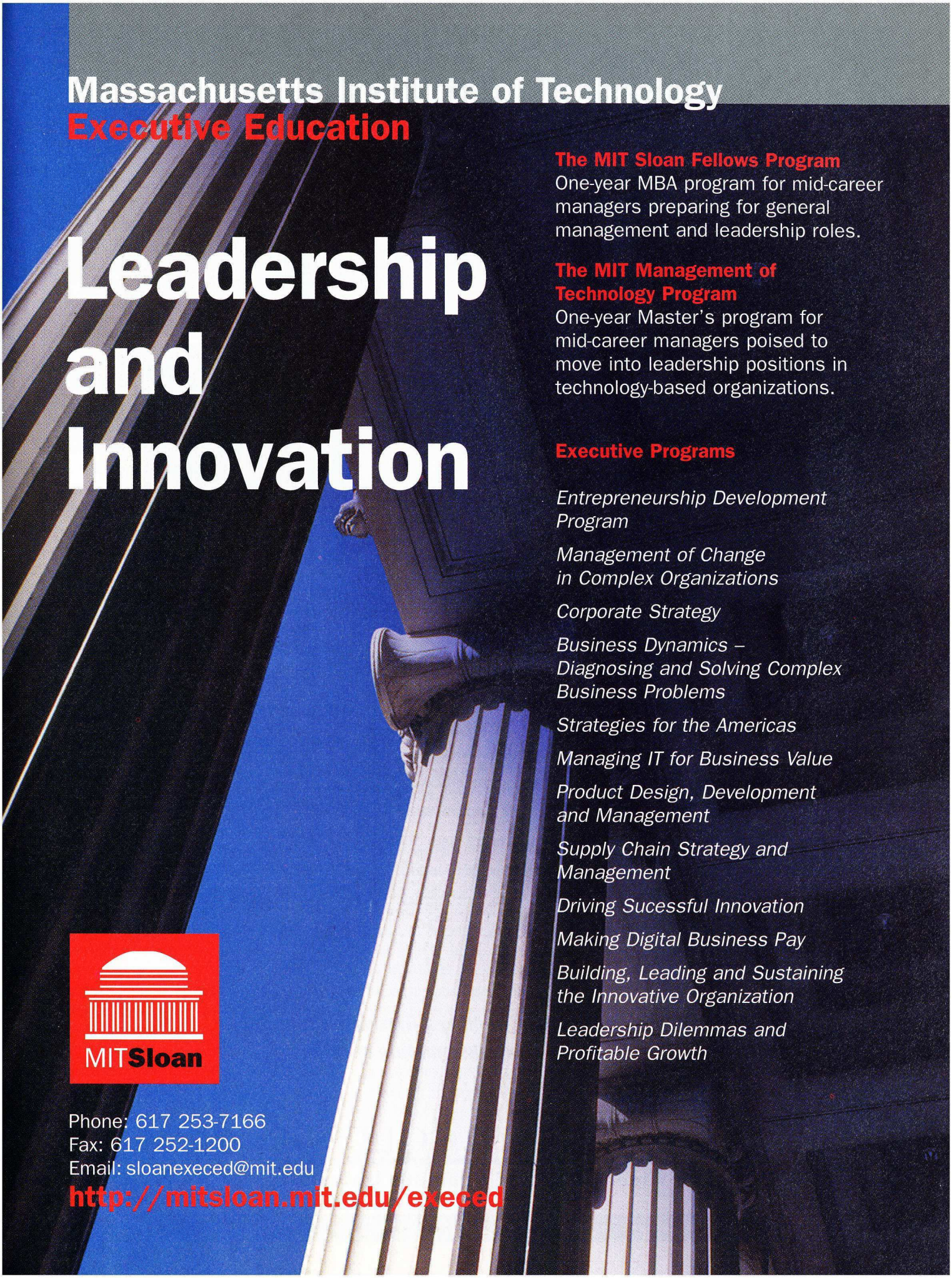
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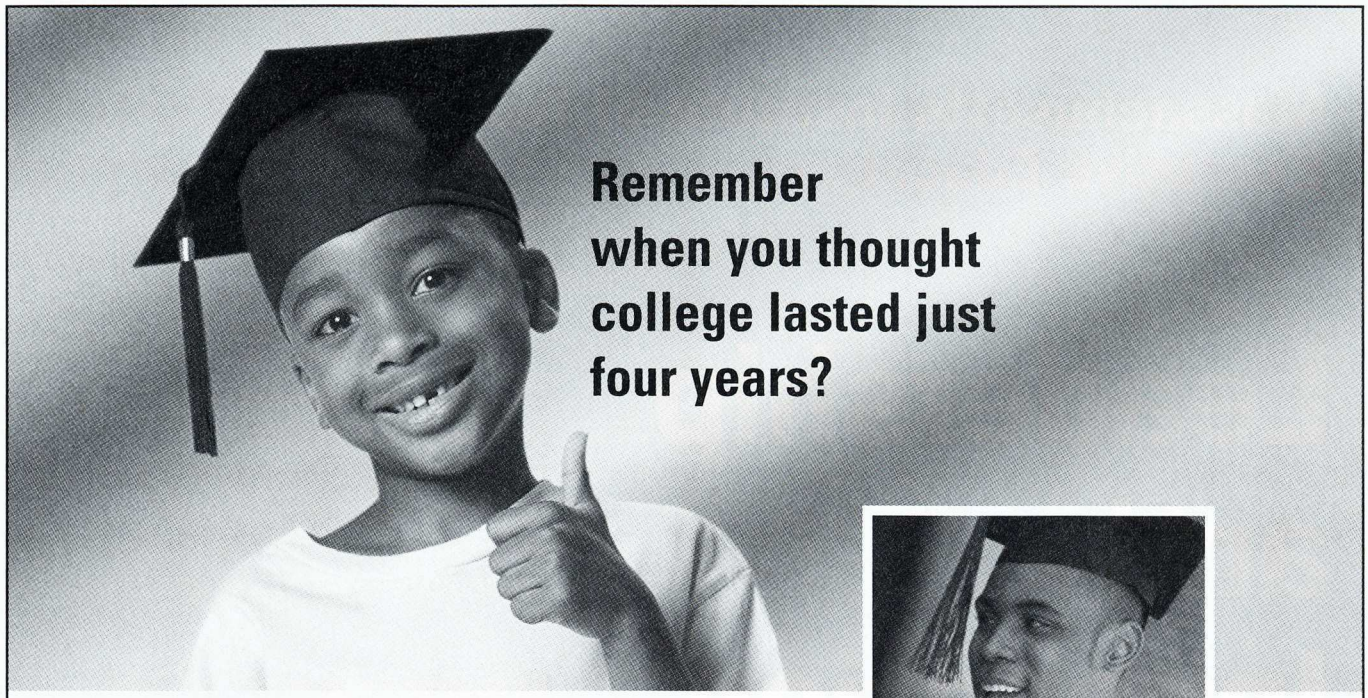
With European executive education programs gaining steam, it makes sense to consider their offerings. Why might a European-based program better suit your needs? What unique perspectives could be gained by study abroad?

European EMBA programs tend to be shorter than their US based counterparts – 12 to 15 months instead of the two-year model more common in the United States. The core topics – leadership, marketing, finance and innovation – tend to be similar, although there are always legal and regulatory differences overseas.

But European schools also have a more international flavor, says George Yip, the associate dean of the London Business School. "There is no dominant nationality," he points out. "The typical study group of six people could well have six nationalities," letting students draw from a rich vein of global experience.

Perhaps this is why many top U.S. business schools have formed partnerships with European schools. Wharton, for example, has a partnership with INSEAD, based in France and Singapore. And New York University's Stern School of Business along with the London School of Economics and HEC Paris Graduate Business School offer a 16-month joint EMBA program called TRIUM. Another example of trans-Atlantic collaboration ties Cambridge, MA and Lausanne, Switzerland. MIT's Sloan School of Management in partnership with the International Institute for Management Development – IMD offers one-semester courses such as "Leadership Dilemmas for Profitable Growth: A Top Executive Forum" and "Driving Strategic Innovation".


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Executive MBAs. The classic MBA is offered on a part-time basis for midcareer executives. Program length generally ranges from one to two years. The Sloan School of Management at MIT offers a one-year Management of Technology program that helps technology-oriented executives learn broader management skills.

CHOOSING A PROGRAM

"First, pick a school that's good at executive education," says Yip. The United States has hundreds of programs, and Europe has about 20 top schools, he says. There are a number of further steps that can help narrow the field to the best fitting programs. Consider the following:

Analyze your skill set. What skills are you trying to add? Is it something focused, such as financial or negotiation skills, or more broad-based managerial expertise? The course you choose should reflect your need.

For example, Lai Wong, an information technology program manager at Hewlett-Packard in Palo Alto, Calif., took a two-week executive education course because he needed to beef up his expertise in general management topics. "It was an incredible learning experience for me. I was exposed to many nontechnical areas, including decision making, strategic management, financial analysis, negotiations and intergroup relationships. It was like a mini-MBA for me."

Ask opinions of people you respect. Look at yourself critically and also ask questions of people you know and trust. Where are your natural talents strongest? Are there areas where you are more deficient? The idea is to know what you don't know.

Be realistic about time. Do you have time to take an entire year from work to devote to education, or can you only squeeze in classes at night? Time constraints will not only drive the choice of program, but what school you choose, points out Yip. Prospective students need to choose schools that fit into their current lives. Motorola's Brennan, for example, chose the short program because he just didn't have time for an EMBA program.

Examine your company's needs. Is your company small or global? Does it make a practice of posting executives overseas, as Proctor & Gamble does? If so, you might consider a program with international flavor, such as the ones offered at top European business schools, including London Business School and INSEAD, based in France and Singapore. In fact, the popularity of global executive education is growing in leaps and bounds. INSEAD landed as the number two school on *BusinessWeek*'s ranking of executive education programs. Additionally, the London Business School, IMD in Switzerland and Spain's IESE Business School in Barcelona also landed on the magazine's list of top 10 schools.

Executive education programs require commitment – both of time and money. But with the economy continuing to struggle, it makes sense to take advantage of all opportunities for advancement. And learning new skills could make the difference between a fulfilling career and treading water.

Carol Hildebrand is a freelance writer based in Wellesley, Mass. She can be reached at childebrand@attbi.com.

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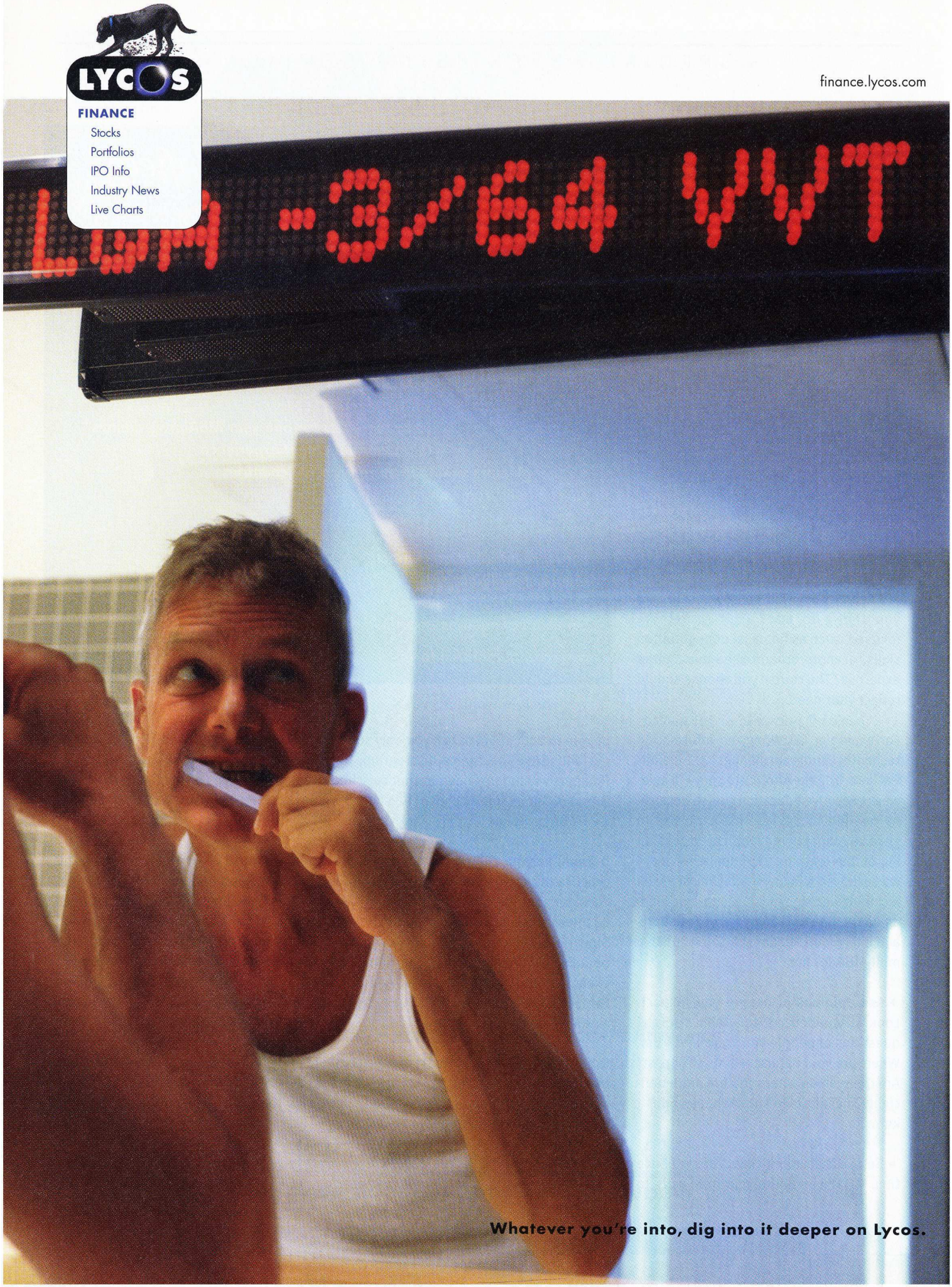
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The 900 MHz technology achieves a greater than 70dB signal-to-noise ratio, allowing the headphones to deliver performance with less outside noise. The headphones have a built-in volume control and are designed for the ultimate in extended-wear comfort.





Get an earful. The Surround Sound Wireless Headphones incorporate a Dolby Digital processor and surround sound headphone technology to create an acoustic environment that is very similar with that of a movie theater or a live musical performance. Their 900 MHz technology achieves a greater than 70 dB signal-to-noise ratio, allowing the headphones to deliver an ultra-quiet performance. This "silence" is essential in conveying the full impact of the movie soundtracks, including the subtle background effects, which can be presented with the most accurate imaging and realism.



The headphones have accurate push-button tuning, battery charging on the base, and allow up to three audio inputs at the rear: two digital and one analog.



The Surround Sound Wireless Headphones provide high-quality sound reproduction with deep, powerful bass and clearly defined highs. Their features combine to make one amazing movie experience. The Surround Sound On/Off switch allows for alternating between virtual Surround Sound for multi-channel sources (like DVDs or home theater receivers) and direct stereo for 2-channel material (like VCRs or music CDs). They have accurate push-button tuning, charging on the base, and allow up to three audio inputs: two digital and one analog.

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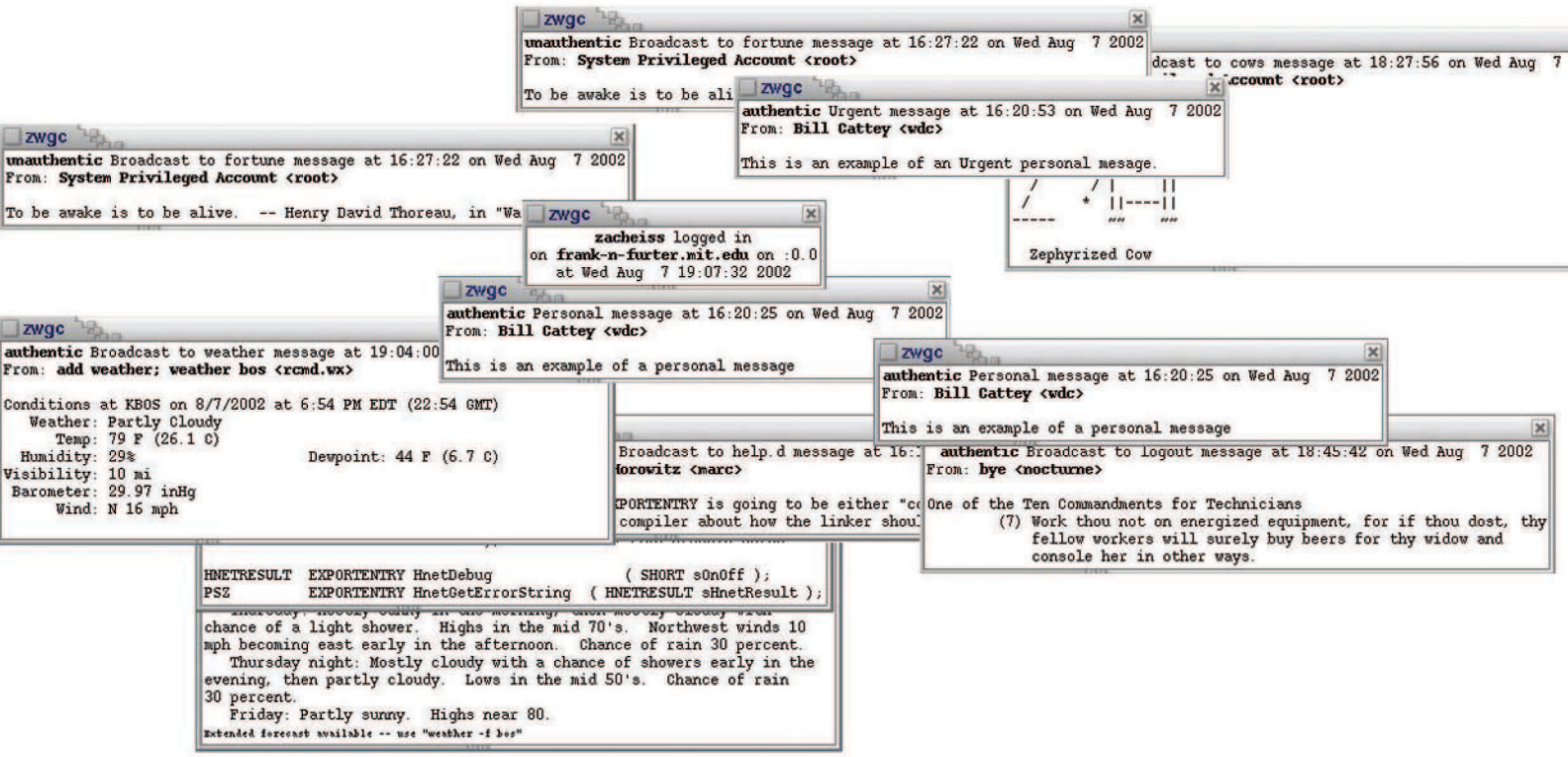
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I'VE GOT TO GET A MESSAGE TO YOU

Instant messaging started as an MIT computer-science department project

More than 34 million people subscribe to America Online, AOL Time Warner's giant Internet-service provider. Many of them were attracted by the AOL Instant Messenger, which lets users send short messages via the Internet to friends and family, nearly instantaneously. Yahoo! and other companies market their own messengers—with millions more users. Not bad for a technology that began in the late 1980s as a small notification system in MIT's computer science department.

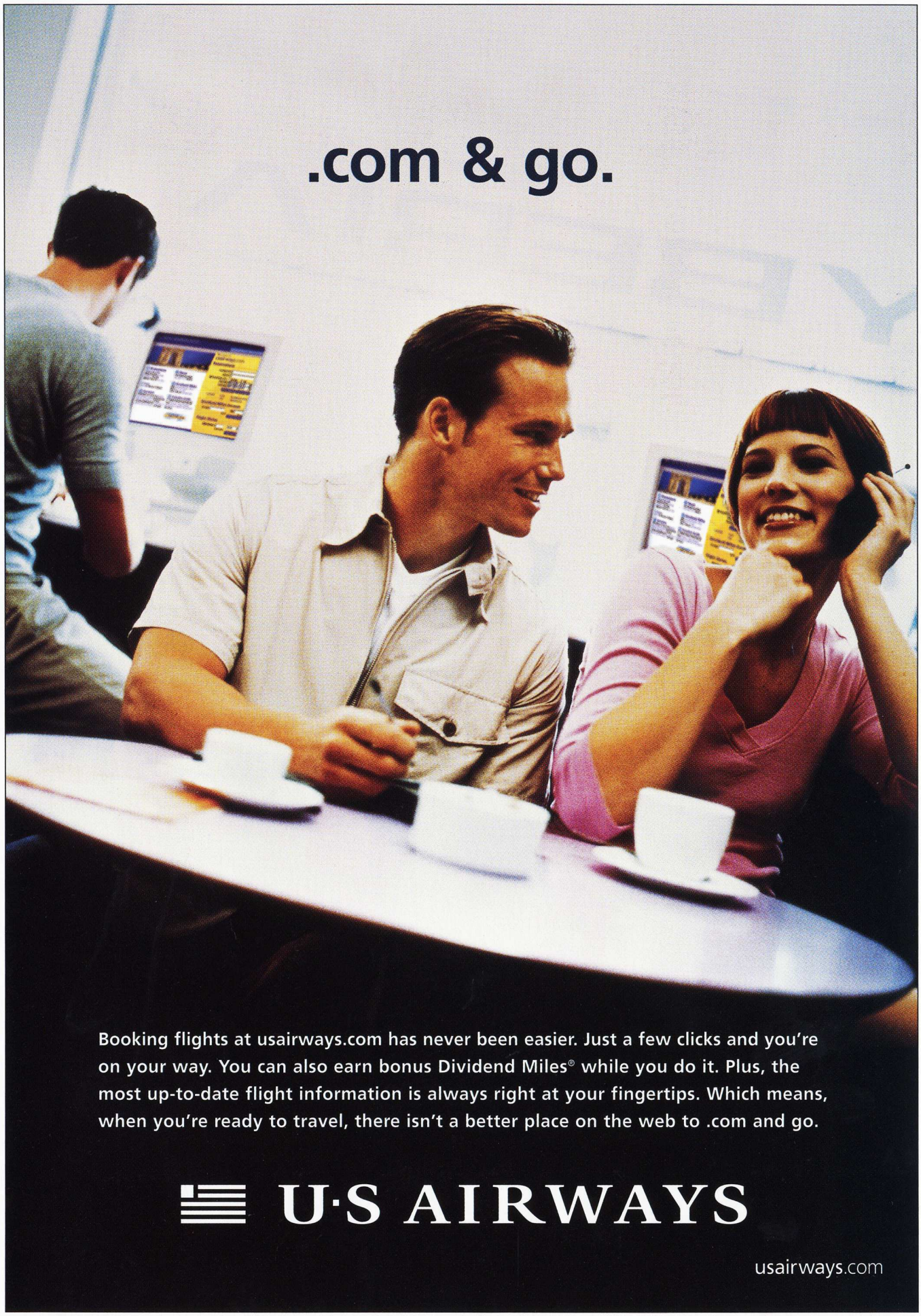
In 1983 MIT's Laboratory for Computer Science kicked off Project Athena, a network of workstations and servers for undergraduate use. By 1987, there were thousands of workstations and several servers, and it became hard to quickly get users vital messages, such as warnings that a building's network was about to go down. Administrators needed something faster than e-mail, which could take hours to deliver—making it useless as a warning tool. So a team led by C. Anthony DellaFera began work on Zephyr, the first widely used instant-messaging system. It was deployed in 1988. Users could "subscribe" to different types of messages—viewing all warnings regarding a particular server, for example, or all messages sent out by a specific person.

Though Zephyr was intended to send system status notifications and alerts like "you have new e-mail," students started to use it to pass messages amongst themselves. When a user logged on, notifications went out to anyone who cared. Friends could send that user messages, which would pop up in separate windows on her screen, and she could answer right back. Participants could even create automatic response notices, saying they had briefly left their desks. (All of these features are central to today's instant-messaging programs.) Zephyr quickly became a standard campus-communication method. "I know quite a number of people who courted using Zephyr," says Robert S. French, one of Zephyr's creators.

Zephyr-like programs were soon adopted by other universities. By the early 1990s, "chat rooms," which used some aspects of Zephyr, became popular among the general public, and in 1996, the Israeli firm Mirabilis put out a free instant-messaging utility called ICQ ("I seek you"). Mirabilis was bought by America Online in 1998. Today, instant-messaging software is used to exchange sound and image files, as well as messages, around the world. The message? Instant messaging is here to stay. —*David Rapp*

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